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Virginia

# Alternatives to Methyl Bromide: Assessment of Research Needs and Priorities

Proceedings from the USDA Workshop  
on Alternatives to Methyl Bromide

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Department of  
Agriculture**



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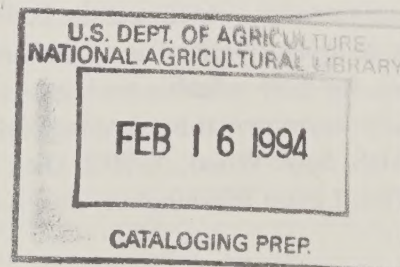
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The views and opinions herein do not necessarily reflect those of the USDA, but rather those of the workshop participants.

## Preface

The *USDA Workshop on Alternatives to Methyl Bromide* report details the assessment of research needs and priorities that must be addressed to find suitable substitutes for methyl bromide. Methyl bromide is used widely as a soil and postharvest commodity fumigant to control insects, weeds, and soil pathogens including nematodes. Worldwide production of methyl bromide is about 63,000 metric tonnes (140 million pounds) per year, with a little more than 58 million pounds (41percent) sold in North America for agricultural-related purposes (Watson et al. 1992, NAPIAP 1993). Approximately 45 million pounds are used in the soil to manage a wide range of pests and pathogens; 5 million pounds are used for postharvest and quarantine treatments; and an additional 5 million pounds are used in structural pest control for conveyances and buildings.

The U.S. Environmental Protection Agency (EPA), in response to concern about data suggesting methyl bromide as a potential ozone-depleting chemical, has proposed to eliminate its production and importation by 2000, pursuant to section 602 of the Clean Air Act. In February 1992, the National Agricultural Pesticide Impact Assessment Program (NAPIAP) conducted a benefit analysis and concluded that unless satisfactory substitutes for methyl bromide are found, its loss will have a serious negative impact on U.S. agriculture. An Ad Hoc Committee composed of representatives from the Agricultural Research Service (ARS), Forest Service (FS), Cooperative State Research Service (CSRS), Animal and Plant Health Inspection Service (APHIS), Agricultural Marketing Service (AMS), Foreign Agricultural Service (FAS), Office of the Assistant Secretary for Marketing and Inspection, and the Global Change Program Office was formed to address this impending crisis. As part of this review, the committee organized a USDA Workshop on Alternatives to Methyl Bromide, June 29 - July 1, in Arlington, Virginia. Approximately 250 persons from government, academia, and the private sector, including more than 100 scientists, attended the meeting.

This workshop was organized into nine concurrent sessions covering all pre- and post-harvest commodities reliant on methyl bromide. The following issues were addressed: (1) problems related to commodities and their pests, which are likely to arise with the phaseout of methyl bromide; (2) existing and emerging alternatives to methyl bromide including biological, chemical, physical, and others; their limitations, adaptability, efficacy and gaps in knowledge on the effectiveness of these alternatives; and (3) short- and long-term high- priority research needs and appropriate approaches.

The primary aim of the USDA Ad Hoc Committee is to provide recommendations for action plans to develop the necessary research and team effort that will provide environmentally and publicly acceptable alternatives to methyl bromide. The alternative technologies developed will support the implementation of State and Federal action and regulatory programs.

The USDA Ad Hoc Committee expresses its gratitude and appreciation to the workshop attendees for openly sharing information on research activities at the Federal and State level related to substitutes or alternative technologies for methyl bromide replacement. The committee is especially thankful to representatives from universities, Federal, and State agencies, for their valuable exchange of information. The committee would also like to thank the following who were especially instrumental in planning and organizing this workshop: Eric Jang, ARS; Hei-Ti Hsu, ARS; Millie Rosenthal, ARS; Scott Wood, APHIS; Dick Smith, FS; Steve Fraedrich, FS; Linda Greczy, USDA Global Change Program Office; Levon Washington, USDA Global Change Program Office; and Ken Dorschner, CSRS (retired).

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# EXECUTIVE SUMMARY

## INTRODUCTION:

The U.S. Department of Agriculture (USDA) convened a Workshop on Alternatives for Methyl Bromide from June 29 to July 1, 1993, in Arlington, Virginia. Participants in the workshop included more than 100 scientists from the Agricultural Research Service and the Cooperative State Research Service of the USDA. Non-participating observers at the workshop included representatives from other State and Federal regulatory agencies and various sectors of the U.S. agricultural industry. The objectives of the workshop were to:

- evaluate the existing and potential alternatives for methyl bromide uses as a postharvest commodity and quarantine treatment, and as a soil fumigant to control agricultural pests; and
- identify research needs and priorities to develop effective alternative pest management strategies that do not rely on the use of methyl bromide.

The workshop consisted of nine working groups. Four of these considered alternatives to methyl bromide for postharvest commodity and quarantine treatment, and five considered alternatives to methyl bromide for soil fumigation treatment. These working groups were organized by commodities as follows:

### Postharvest Commodity and Quarantine Working Groups

- Dried Fruits and Nuts
- Grains and Milled Products
- Non-food Products (including Ornamental Plants and Forest Products)

### Soil Fumigation Working Groups

- Strawberry
- Tree Fruits and Nuts, and Other Small Fruits
- Solanaceous Crops
- Forestry, Nursery, and Horticultural Crops
- Leafy and Other Vegetables

In addition to the collective knowledge and experience of the participants, resources for the workshop also included two recent USDA publications.

These were *Methyl Bromide Substitutes and Alternatives: A Research Agenda for the 1990s*, United States Department of Agriculture, January 1993, and *The Biologic and Economic Assessment of Methyl Bromide*, United States Department of Agriculture, National Agricultural Pesticide Impact Assessment Program (NAPIAP), April 1993.

The U.S. Clean Air Act (Section 602) requires that any substance identified as ozone depleting be withdrawn from production, importation, and use in the United States by 2000. Under the U.S. Clean Air Act, there are no special-use exemptions for agricultural or other uses of methyl bromide. In 1993, the USDA developed a general research agenda to address methyl bromide replacement and improvement of technologies to reduce or eliminate methyl bromide emissions into the atmosphere.

The participants in this workshop specifically evaluated the status of a variety of existing and potential alternatives and approaches to methyl bromide for management of postharvest and quarantine pests, and soilborne plant pests. They further identified research needs and priorities, in both the short and long term, to develop effective strategies that do not rely on the use of methyl

bromide to manage a wide range of agricultural pests at economically acceptable levels.

The workshop was specifically not a forum to discuss and debate the merits or shortcomings of proposed regulatory decisions about the fate of methyl bromide use in the United States by the year 2000. It also was not the purpose of this workshop to explore ways to reduce methyl bromide emissions into the atmosphere.

A general consensus of the workshop participants was that no approach is currently available that will achieve the same level of broad-spectrum pest management as methyl bromide, either for postharvest, commodity, quarantine treatment, or soil fumigation applications. Chemicals and non-chemical approaches that are available can provide some level of agricultural pest management, but generally with narrower activity than methyl bromide, during crop production and postharvest. In addition, these generally result in lower crop yields and quality.

## **WORKSHOP FINDINGS**

### **Alternatives to Methyl Bromide for Postharvest Commodity and Quarantine Treatment**

Postharvest commodities, including non-food and quarantine treatment products, considered by these working groups are infested by a wide range of pests, including beetles, weevils, moths, caterpillars, thrips, leaf miners, wasps, termites, cockroaches, fruit flies, bruchids, homopterans, bark and wood boring insects, diapausing pink bollworm larvae (in seed), ants, nematodes, ticks, mites, snails, and various stored product insects, fabric pests, and "hitchhikers." The scope of these pest problems is local, regional, national, and international depending upon the specific pest-commodity combination. The existing, most feasible, and potential alternatives to methyl bromide for managing these pests are generally similar for all of these commodities. These include chemical and non-chemical (physical and biological) approaches.

Existing chemical alternatives include phosphine, chloropicrin, and hydrogen cyanide. Potential chemical alternatives include dichlorovos, pyrethroids, sulfur dioxide, carbon monoxide, ethyl and methyl formate, acetaldehyde (for surface hitchhikers), residual chemicals such as Actellic® and Reldan®, biorational pesticides (insect growth regulators), chitin inhibitors, hormone mimics, borate, and mating and behavior disruption chemicals including pheromones.

Non-chemical alternatives involve biologically based and physical methods.

Existing physical alternatives include irradiation, modified atmospheres, cold and hot treatments, and combination treatments. Potential physical alternatives include focused microwaves, engineering of facilities (sealing of equipment and structures), and optimization of modified environment. Potential biologically based methods include genetically engineered resistant host plant varieties, biological control (microbes and parasites/predators), as an integral part of the integrated pest management methods and expert systems.

Generally, these non-chemical alternatives are environmentally compatible pest management strategies. The effectiveness of many of these approaches is largely unknown but it is unlikely they will provide the level of control needed for quarantine situations. The new technologies and new applications of existing alternatives will have to be continually reviewed to provide new and more efficient treatments.

### **Research Needs and Priorities**

Research needs vary greatly with the type of commodities and their pest problems. The following cross-cut needs were recognized by all four groups.

#### *High Priority, Short Term*

Evaluate and implement existing chemicals for disinfestation of postharvest and quarantine commodities. Develop improved formulation and application technology of the existing chemicals.

Optimize parameters for existing modified atmosphere, hot and cold treatment, and irradiation methods.

Develop suitable engineering components in support of existing and potential alternatives for disinfestation of postharvest and quarantine treatment commodities.

Develop safe, environmentally sound integrated pest management strategies and expert systems based on available information.

Develop improved pest detection and monitoring methods, including discrimination of irradiated insects and develop action thresholds.

Develop non-host packing and shipping and storing materials for export of commodities.

#### *High Priority, Long Term*

Develop and evaluate new synthetic chemicals for postharvest commodities and quarantine treatment.

Develop improved chemical pesticide formulation and application technology.

Develop biorational pesticides.

Develop basic biology and physiology data bases on pests.

Automate available useful technologies for detection, sorting, and certification; determine feasibility and limits of the selected systems.

Improve formulation and delivery systems of microbial/biological control agents.

Develop system approaches to attain pest-free commodities without the use of direct treatments.

#### *Medium Priority, Short Term*

Optimize application of existing space treatment (aerosols) chemicals and register additional chemicals.

Develop sanitation methods appropriate for different commodities and their pests.

Evaluate microwave heating methods for disinfestation of non-food commodities.

#### *Medium Priority, Long Term*

Identify, evaluate, and develop biological control agents suitable for disinfestation and control of postharvest commodities.

Evaluate mating disruption and behavior modifying chemicals, especially concentrations, persistence, and formulation.

Identify, isolate, and characterize useful genes with high expression levels for pest genetic manipulations of pests.

### **Alternatives to Methyl Bromide for Soil Fumigation**

All commodities considered by these working groups are affected by a wide range of soilborne plant pests, including plant pathogenic fungi, plant parasitic nematodes, phytopathogenic bacteria, insects, and weeds. The scope of these pest problems is local, regional, and national depending upon the specific pest-commodity combination. The existing and potential alternatives to methyl bromide for managing these pests are generally similar for all of these commodities. These include chemical and non-chemical approaches. Management of soilborne pests of these commodities will need to involve a combination of these alternative approaches.

Existing chemical alternatives include chloropicrin, Vapam®, Telone II®, Telone C-17®, and Basimid®. Potential chemical alternatives include sulfur dioxide, sodium tetrathiocarbonate, and anhydrous ammonia. Finally, naturally occurring plant products and biorational pesticides are also potential alternatives.

Non-chemical alternatives involve biologically based and physical methods. Biologically based methods include host crop resistance, biological control, and cultural practices. Generally, these are environmentally compatible pest management strategies. However, the effectiveness of many of these approaches is largely unknown. These approaches for soilborne pest management need to be developed for specific applications.

Genetic resistance of crop hosts is one of the most effective means of controlling plant pests during production, and should be a component of any integrated pest management strategy or program.

The range of cultural practices that can be used, or developed for use, to manage soilborne plant pests of these commodities include use of pathogen- or pest-free planting material, changing to annual production systems, containerized production systems, crop rotations, fallowing, use of trap crops and mulches, intercropping, improved planting site selection and preparation/modification, improved soil water management, improved tillage practices, use of soil amendments, and use of soilless media (in containerized and greenhouse situations) or other soilless culture (tissue culture, hydroponics).

Physical methods that can be used, or developed for use, to manage soilborne plant pests include soil pasteurization (soil solarization, steam, electronic heating, composting, irradiation), flaming, or cultivation of post emergence weeds.

## **Research Needs and Priorities**

### *High Priority, Short Term*

Evaluate and implement existing chemicals for soilborne plant pest management.

Develop improved chemical pesticide formulation and application technology.

Evaluate existing germplasm for resistance to the major soilborne plant pests.

Develop safe, environmentally sound integrated soilborne pest management strategies based on available information.

Develop pathogen-free planting material.

Develop improved pest risk assessment methods, including improved pest detection and identification, and action thresholds.

Develop new crop and culture production systems.

### *High Priority, Long Term*

Develop and evaluate new synthetic chemicals for soilborne plant pest management.

Develop biorationals.

Identify, evaluate, and develop naturally occurring chemicals to manage soilborne plant pests.

Develop improved chemical pesticide formulation and application technology.

Identify, evaluate, and develop soilborne plant pest resistant germplasm, and incorporate this genetic resistance into commercial cultivars.

Develop pathogen-free planting material.

### *Medium Priority, Short Term*

Develop effective soil pasteurization technology based on soil solarization, electric heating, and electronic heating with radiofrequency power.

### *Medium Priority, Long Term*

Develop improved cultural practices to manage soilborne plant pests.

Identify, evaluate, and develop biological control agents for soilborne plant pest management.

### *Low Priority*

Develop pest-resistant hosts via biotechnology.

# POSTHARVEST AND QUARANTINE

## Session I: Dried Fruits and Nuts

Discussion Group: *Chairs*- Patrick Vail, Peter Witherell; *Participants*- Patrick Gomes, Charles Huxsoll, Tobi Jones, Beth Mitcham, Tom Rumsey, Don Silhacek, Edwin Soderstrom

### INTRODUCTION

The commodities addressed in this section include two groups - nuts and dried fruits - both possessing diverse physical and chemical characteristics. These commodities may be stored for extended periods of time, both before and after processing. Sources may be both domestic and foreign, and quarantine treatments may be necessary. The alternatives will likely be more insect and commodity specific than current practices. Although not specifically mentioned, it is implied that new technologies and new applications of existing alternatives will be continually reviewed to provide new and more efficient treatments. In the following tabulation, the major United States crops and pests are italicized.

### COMMODITIES, PEST PROBLEMS, AND SCOPE

The commodities include nuts (*almond*, beechnut, betel nut, Brazil nut, butternut, cashew, chestnut, *filbert (hazelnut)*, hickory nut, *macadamia nut*, *pecan*, *pistachio*, black walnut, *English walnut*, coconut, *peanut*, pine “nut”, sunflower “nut”, coffee bean, cocoa bean, cola nut) and dried fruit (*raisin* (including sultana), *prune*, *pear*, *apple*, *apricot*, date, banana, *fig*, coconut, *peach*, *nectarine*, *pineapple*, *tomato*, *mango*, *papaya*, *blueberry*, *cranberry*, and *raspberry*).

Nuts are infested by a wide range of insect pests including: rusty grain beetle, flat grain beetle, merchant grain beetle, red flour beetle, confused flour beetle, corn sap beetle, black fungus beetle, cigarette beetle, hairy fungus beetle, dermestid beetles (various spp.), *khapra beetle*, drugstore

beetle, saw toothed grain beetle, *Curculio nasicus*, pecan weevil, small chestnut weevil, rice weevil, groundnut bruchids, *Indianmeal moth*, *navel orangeworm*, *codling moth*, almond moth, warehouse moth, hickory shuckworm, tobacco moth, raisin moth, peach twig borer, seed infesting bugs, and *exotic fruit flies*.

Dried fruits are infested also by a wide variety of insect pests including: Dermestids (various spp.), *khapra beetle*, several spp. of *sap beetle*, saw toothed grain beetle, merchant grain beetle, dried fruit beetles, confused flour beetle, cigarette beetle, coffee bean weevil, *exotic fruit flies*, vinegar flies, earwigs, ants, dried fruit mite, common grain mite, *almond moth*, *Indianmeal moth*, raisin moth, warehouse moth, carob moth, and dried fruit moth.

The scope of these insect pest problems is international. Depending upon the commodity, some of these pests are regional or national problems. The pests can be found any time after dried fruits and nuts are harvested and until they are consumed. In addition to protection of the unprocessed commodity, pest control procedures are needed also for storage, shipping, and marketing of finished products. Reinfestation may occur in domestic or foreign storage, transit, marketing channels, and consumer storages. Quarantine treatments may be required for both domestic (*exotic fruit flies*, *codling moth*) and foreign commodities (*khapra beetle*). The average yearly production (domestic) of the major dried fruits and nuts exceeds 1,243,094 tons, with a farm value of \$1,694,439,000. The farm value for peanuts is approximately \$1billion and annual production is approximately 1 million tons. Obviously, these high-value commodities require high levels of insect control, particularly when value added costs are considered. About 35% of domestic production is exported. Currently, 100% of domestic dried fruits and nuts are treated at least once with methyl bromide or phosphine, and the frequency depends

on the time interval in storage prior to processing (over one year, in some cases). The loss of methyl bromide will have a severe adverse impact on the insect control practices currently used, and secondary or indirect effects on storage, handling, processing, and domestic and foreign markets must be considered.

Of particular concern are the extended times for application and treatment, and reduced efficacy for a number of alternatives. No single alternative has been demonstrated to provide the high levels of mortality required for quarantine. Thus several treatments may be needed to provide the security now afforded by methyl bromide. The development of quarantine treatment replacements will require long-term efforts not only for developing the data but also for gaining regulatory acceptance. Some commodities may be damaged by the alternatives proposed; thus, the alternatives may be commodity specific. It is likely a systems approach incorporating several alternatives will be required to provide adequate protection/quarantine security. Considerable engineering and technology transfer will be required for the alternatives to be economical and in place on a timely basis.

## **ALTERNATIVES TO METHYL BROMIDE: IDEAL ATTRIBUTES**

- Quick mortality (2-24 hr) for most organisms
- Broad spectrum of activity
- No known resistance among pests
- Cost effective
- Good penetration of commodities
- Effective at relatively low temperature
- Easy to use
- Non-flammable and non-explosive
- Recognized world-wide as an effective treatment
- Does not damage the product
- Public, regulatory, and legal acceptance
- Safe to use
- Environmental impacts minimal or none
- Readily available
- Adaptable to many scales of use

## **EXISTING ALTERNATIVES**

*Chemical Methods:* No quarantine treatments for dried fruits and nuts are approved using existing alternatives. Irradiation and controlled atmospheres are not currently used by industry. See disadvantages below.

*Phosphine:* This fumigant is used to control stored product insect pests. No further research is needed. Major *advantages* include: registered; efficacious for relevant pests; relatively cost effective; internationally accepted; and low residues. Major *disadvantages* include: resistance demonstrated in some pests; fumigation time of 3-5 days; off-flavor in some commodities; not effective under 50° F; corrosive to copper and alloys; less than adequate commodity penetration; long-term availability questionable; and not accepted for quarantine.

### **Physical Methods**

*Irradiation:* Ionizing radiation is used to control insects. Little research is required. Major *advantages* include: demonstrated efficacy; absence of residues; not temperature dependent; and can treat sealed containers. Major *disadvantages* include: generally accepted by international trade and regulatory agencies but perceived consumer acceptance problems; high capital costs; not a “stand-alone” treatment; kill not immediate; logistics of use; commodity immediately susceptible to reinvasion; and not accepted for quarantine

*Controlled Atmospheres:* Modification of air space to suffocate insects (low oxygen, high carbon dioxide, or high nitrogen or hypobaric pressure) by purging or displacement. Some research on sealing and efficiency may be required. Major *advantages* include: absence of residues; proven efficacy; and price of nitrogen technology decreasing. Major *disadvantages* include: needs well-sealed chambers; higher capital costs; slow acting; temperature dependent; no residual activity; not accepted for quarantine; will require training on the process and its variables; and unless maintenance atmosphere levels are used, commodity is immediately susceptible to reinfestation.

## POTENTIAL ALTERNATIVES

*Basic biology and physiology:* Develop data on insect commodity preferences and effect of commodity and environmental conditions on insect growth and development, survival, and reproductive capacity. Determine efficacy of proposed treatments listed below as related to above listed factors and develop data base for modeling and subsequent integrated management systems. Major *advantages* include: help in timing of treatment; identification of new alternatives; and provide methods to enhance efficacy and reduce number of treatments required. Major *disadvantages*: by itself does little to abate pest presence and infestation.

*Integrated Pest Management Systems:* From data bases obtained for potential alternatives listed below, develop optimal strategies for their use and integration into pest control systems. Major *advantages* include: predictability and reduction of need for specific control systems. Major *disadvantages* include: dependence upon control strategies used; more emphasis on sanitation and source reduction is assumed in integrated pest management systems; cost and additional training; and difficult for regulatory agencies to monitor.

*Detection, Sorting, Certification:* These include methods to reduce or determine infestation levels to reduce or eliminate need for specific treatments. Major *advantages* include: environmentally benign; reduce need for treatments; and improved worker safety. Major *disadvantages* include: requires high technology; unknown costs; and regulatory acceptance.

*Optimized Controlled Atmospheres:* Combined with the following potential alternatives, this could reduce application time, and cost required for use. Major *advantages* include: decrease in treatment time and/or increase in efficacy; and may allow use for quarantine. Major *disadvantages* include: (See Controlled Atmospheres above.)

*Optimized Hot and Cold Treatments:* Major *advantages* include: no residues; public acceptance;

environmentally safe; and worker safe. Major *disadvantages* include: not accepted for quarantine treatment; time may affect quality; needs uniformity of application; and no residual activity.

*Microbial Control:* This involves use of insect-specific pathogens for control. This method can be used primarily for long-term protection after an initial disinfestation treatment. Major *advantages* include: no chemical residues; specificity; safe; long-term protection; and reduce number of treatments required. Major *disadvantages* include: may be too specific; registration and labeling issues; not readily available; and acceptance by consumer, commodity, and regulatory agencies.

*Insect Growth and Development Regulators:* These include insect hormones or synthetic analogs capable of affecting insect growth, development, and reproduction. These can be used only as protectants. Major *advantages* include: demonstrated effective as a protectant of peanuts, rice, and wheat; host specificity; low mammalian toxicity; and long-term protection. Major *disadvantages* include: not approved for food products; not approved for quarantine; slow acting; and host specificity.

*Classical Biological Control:* This involves use of predators and parasitoids for insect control. This method can be used primarily as a space treatment when commodity is not present. Major *advantages* include: long-term population suppression; specificity; worker safe; and environmentally safe. Major *disadvantages* include: host specificity; availability; not for quarantine; quality control; and not compatible with chemicals. However, insecticide-resistant beneficial insects have been selected.

*Mating Disruption Chemicals:* This control method is based on behavior-modifying chemicals to control insect mating and reproduction. Major *advantages* include: host specificity; compatible with other methods; worker safe; and environmentally safe. Major *disadvantages* include: used only as protectants; not for quarantine use; species specific; and probably will control only low populations.

*Genetic Engineering:* Insertion of specific genetic material into plant genomes (transgenic plant strains) to provide insect control. Major *advantages* include: specificity; no residues; long-term protection; safe; and no energy requirements. Major *disadvantages* include: consumer acceptance; regulatory acceptance; cost of development; and specificity.

*Packaging and Containerization:* This involves use of insect-resistant packaging of bulk and consumer packed goods. This method would be used as a treatment *per se* or after treatment to prevent re-infestation. Major *advantages* include: unitized packaging could limit infestations and losses; can be used in combination with controlled atmospheres, irradiation and other technologies; provide protection in marketing channels; and may eliminate need for large storage facilities. Major *disadvantages* include: problem as to scale; costs; needs to be combined with other technologies; and assurance of low infestations when containerized.

*Engineering:* Many of the alternatives will require considerable engineering research in order to be used efficiently. New methods of application, increased energy efficiency, and sealing methods for existing or new structures will have to be identified or developed. Suitable facilities may need to be designed for use of multiple technologies. Major *advantages* include: helpful in maximizing the efficiency of newly developed control procedures. Major *disadvantages*: none.

### **Chemical Insecticides:**

*Hydrogen cyanide.* Major *advantages*: efficacious against stored products insect pests. Major *disadvantages*: bad public image; explosive and flammable; last resort treatment; and not currently registered.

*Propylene oxide.* Major *advantages* and *disadvantages* are not clear at this time. Research needed; registered for use on processed nutmeats (except peanuts); and not registered for use in California.

*Ethyl formate.* Major *advantages*: efficacious against stored products insect pests; and can penetrate wrappings. Major *disadvantages*: flammable and explosive; not registered for use in California; no current EPA registration; and 72-hour minimum exposure is required for efficacy; corrosive to unpainted metals, especially iron and steel.

*Ethylene oxide.* Major *advantages*: would probably prove efficacious against stored products insect pests, but more research is needed. Major *disadvantages*: flammable and explosive; and registered as a sterilant on spices, but not as an insecticide.

*Malathion.* Major *advantages*: Short Term residue; and history of usage in the grain industry. Major *disadvantages*: odor; surface protectant only; and no penetration.

*Develop chemical protectants.* Space and structure treatments to control storage insect pests. Residual life must be appropriate, safe for consumers and applicators. *Advantages*: long-term protection; and disinfest structures. *Disadvantages*: residues on commodities; applicator hazard; and not acceptable by some consumers.

## **RESEARCH NEEDS**

(short term: to year 2000; medium term: 10 years; long term: more than 10 years)

### *High Priority, Short Term*

Develop basic biology and physiology data bases as described above for integrated pest management systems.

Develop methods to reduce application times of controlled atmosphere treatment for quarantine use, probably in combination with high temperatures.

Develop method(s) to discriminate irradiated insects for regulatory purposes.

Determine available useful technologies for detection, sorting, and certification; determine feasibility and limits of the selected systems.

Optimize controlled atmospheres - develop time/concentration relationships at elevated temperatures (greater than 26.7<sup>o</sup> C); optimize application methods.

Optimize hot and cold treatment methods so that treatments are rapid and have little or no effect on quality; develop new application technologies.

Develop commercially available microbial control agents as protectants.

Determine modes of action of insect growth and develop regulators; develop formulation for long-term control.

Develop improved packaging and containerization technologies with special emphasis on research on practical volumes of commodities for storage, integrity of material over time for protection, influence of environmental factors on integrity of materials, and possibilities for re-use in combination with specific insecticidal treatments.

Develop suitable engineering components in support of priority research needs with special emphasis on problems as to scale, blending of the alternatives into systems, and designing facilities specifically for the use of alternatives.

#### *High Priority, Long Term*

Develop basic biology and physiology data bases as described above.

Develop integrated pest management systems that provide predictable long-term control using developed alternatives.

Determine available useful technologies for detection, sorting, and certification; determine feasibility and limits of the selected systems.

Optimize controlled atmospheres to reduce treatment times, develop time/concentration relationships at elevated temperatures (greater than 26.7<sup>o</sup> C), and optimize application methods.

Develop formulation and delivery systems for microbial control agents; increase efforts to isolate useful pathogenic microorganisms for coleopterans; develop efficacy data.

Optimize hot and cold treatment methods so that the treatments are rapid and have little or no effect on quality; develop new application technologies. Combine with controlled atmospheres to reduce treatment time.

#### *Medium Priority, Short Term - None*

#### *Medium Priority, Long Term*

Conduct surveys of natural enemies of dried fruit and nut pests for classical biological control; determine control potentials of candidate organisms; develop application methods for use; efficacy data.

Establish control levels for mating disruption chemicals; concentrations, persistence, and formulation must be considered.

Isolate useful genes with high expression levels for insect control by genetic engineering.

#### *Low Priority, Short Term - None*

#### *Low Priority, Long Term - None*

## Session II: Fresh Fruits and Vegetables

Discussion Group: *Chairs*- Robert Mangan, Eric Jang; *Participants*- Darcy Axe, John Armstrong, Mary Arpaia, Harvey Chan, Jr., Guy Hallman, Michael Hennessey, Raymond McGuire, James Moy, Lisa Neven, Robert Paull, Krista Shellie, W. Scott Wood.

### INTRODUCTION

Methyl bromide is used extensively for fumigation of fresh fruits and vegetables moving into and out of the United States. In addition, it is used to fumigate agricultural products shipped interstate. The primary use of methyl bromide is to ensure that various quarantine pests are not transported from areas where they currently exist to areas where they do not occur. Certain areas of the United States export significant amounts of fresh fruit to foreign countries (apples, cherries, stone fruits, citrus).

Methyl bromide is used to fumigate imported produce infested with quarantine pests at port of entry when shipped from foreign countries. The numbers and types of pests that may be found in such shipments are extensive. APHIS-PPQ has compiled lists that involve nearly all imported fresh produce and hundreds of arthropod pest species. Introduction of these pests into the continental United States could have an adverse impact on agriculture. The loss of methyl bromide will necessitate the need to find suitable alternatives for all of these pests.

Ten different groups of commodities that currently use methyl bromide and for which alternatives are needed were identified. Commodities were grouped by their horticultural similarity or by pests associated with them. The groups include: apples, citrus, stone fruits, berries and cherries, grapes (imported), bananas, plantains and pineapples (imported), melons, squash and cucumbers (imported), root crops (imported), leafy vegetables,

and avocado. Commodities currently treated in another way (papaya and mango with heat), or those which do not currently have a disinfestation method, were not included.

Several existing and potential alternatives for each of the 10 groups were identified. The characteristics and attributes required of alternatives are the same as described in Alternatives to Methyl Bromide: Ideal Attributes in Session I. The alternative treatment for quarantined pests must meet a mortality factor of 99.9968%, or no more than 3 survivors per 100,000 treated pests. Any breach of quarantine security may allow survivors to mate and successfully colonize in a new location.

### COMMODITY, PEST PROBLEMS, AND SCOPE

#### APPLES AND PEARS

These are infested by codling moth, lesser apple worm, and apple maggot. The scope of these pest problems is regional and export. At present, apples are not ranked as a major export requiring methyl bromide fumigation.

#### Existing Alternatives

*Inspection/certification and Cold Controlled Atmosphere.* Acceptability of an inspection/certification system is not known. Cold controlled atmosphere may be expensive.

#### Potential Alternatives

*Heat, Cold, Combination:* *Advantages:* temperature treatments have been developed for other fruits and vegetables, both temperate and tropical / subtropical; lethality limits are known for many of the pests such as some fruit fly species; and no problems with residue as with pesticides. *Disadvantages:* heat treatments may not be suitable for

many temperate fruits and vegetables, such as berry crops and stone fruits; cold treatments may adversely affect tropical and subtropical fruits; effects of temperature on product tolerance, quality, and shelf-life is not well known; and all treatments lack basic knowledge of both pest and fruit physiology.

*Controlled Atmosphere: Advantages:* controlled atmosphere is used for long-term storage of apples, thus technology exists for implementation of such technology on other fruits; controlled atmosphere treatments may improve shelf life as well as disinfest for pests; and may also be combined with temperature treatments. *Disadvantages:* basic physiological tolerance of controlled atmosphere to many insect species (including fruit flies) is not well understood; treatments tend to be longer in duration than other practices; may not be suitable for some highly perishable commodities such as cherries and berry crops; and basic research must be initiated.

*Pest-free Zones: Advantages:* pest-free zones allow for the shipment of commodities without the need for a direct treatment in most cases; no quarantine treatment is usually necessary; and product quality and shelf life are not reduced. *Disadvantages:* requires extensive knowledge of the pest biology; usually restricted to geographically isolated areas; requires an extensive monitoring and surveillance network and internal quarantine measures; and costs of such measures can be high for limited-production crops.

*Irradiation: Advantages:* shown to be highly effective in killing many pests on several different commodities; provides extended shelf life and decay control at the higher doses; and treatment time is usually short. The doses required to disinfest several fruit fly species in papaya are known and may be similar for other species. *Disadvantages:* not accepted by some countries and states; location of facilities and engineering considerations may limit sites where facilities are built and may require growers to ship their products more than once; and capital costs are currently high.

*Systems Approach: Advantages:* may alleviate or greatly reduce the severity of treatments if pre- and postharvest practices could significantly reduce or eliminate pest from commodity; and incorporates both pre- and postharvest practices to reduce known population levels to meet quarantine security. *Disadvantages:* like pest-free zones, requires extensive knowledge of pest biology, ecology, and physiology to assess meaningful field population levels and develop appropriate treatments (if necessary) that would further reduce infestation.

*Focused Microwaves: Advantages:* may allow on-site treatment of commodity; and mortality is most likely a result of differential susceptibility to heat. *Disadvantages:* capital costs may be high; safety is not known at this time and may involve high health risks; no research or commercial facilities are available; and commodity tolerances are unknown.

*Automated Inspection:* This may improve detection for inspection and certification, and possibly reduce costs.

## **Research Needs**

### *High Priority, Short Term*

Regulatory approval of existing alternatives.

Accelerate testing of heat, cold, controlled atmosphere, and combinations.

### *High Priority, Long Term*

Pest-free zones.

Systems approaches.

### *Medium Priority, Short Term*

Additional work on product quality and shelf life extension (pears).

### *Medium Priority, Long Term*

Focused microwaves.

Genetic manipulation of pests for treatment susceptibility.

## **STONE FRUITS - PEACH, PLUM, NECTARINE, APRICOTS, CHERRY**

These are infested by a wide range of pests, including codling moth, mediterranean fruit fly, western cherry fruit fly, walnut husk fly, peach twig borer, oriental fruit fly, oriental fruit moth, and plum curculio.

The scope of the problem is export, import, and regional. Cherries, nectarines, and peaches combined are the most significant fruits currently exported that require methyl bromide treatment. No satisfactory alternatives are approved for export markets. Establishment of fruit flies in California would require quarantine treatments for interstate shipments.

### **Existing Alternatives**

There are no approved treatments for the most important exports (cherries, peaches, nectarines for codling moth and oriental fruit moth) to important export markets. Cold treatments (fruit flies), and pest-free periods or non-host status (walnut husk fly) are discussed above.

Pest-free period is currently accepted by some countries for walnut husk fly. The attributes of cold treatments are listed below.

### **Potential Alternatives**

*Irradiation, Inspection/Certification, Heat/Cold, Controlled Atmospheres* (above).

*Resistant varieties: Advantages:* Development of resistant varieties or cultivars through classical breeding or bioregulation, as well as longer term molecular approaches, may preclude the need to treat fruits and vegetables for disinfestation. *Disadvantages:* Identification of factors that provide for resistance or non-suitability for one characteristic may open up vulnerabilities to other problems (pests, quality, self life, disease). Few cultivars

have been found which meet the standards of all scientific disciplines.

Irradiation is reported to work well with stone fruits. Inspection/certification is most acceptable as part of a systems approach (nectarines, cherries). For controlled atmospheres, some data is available relative to nectarines. Heat treatment can cause serious problems for shelf life and fruit quality for cherries. Cold treatment works well on fruit flies. Heat/controlled atmosphere combinations have not been tested for fruit flies. Resistant fruit varieties offer long-term solution.

### **Research Needs**

#### *High Priority, Short Term*

Alternative treatments for codling moth on cherries; systems approach, heat/cold combinations, and irradiation.

Research on alternative treatments to control fruit flies in stone fruits (temperature, controlled atmosphere, irradiation).

#### *High Priority, Long Term*

Develop systems approaches including host status, pest-free zones.

## **GRAPES**

This commodity is infested by a few pests such as mites and white fringe beetle. The scope of these pest problems is regional and imports.

### **Existing Alternatives**

There is no existing alternative to methyl bromide treatment of grapes.

### **Potential Alternatives**

Carbon dioxide/sulphur dioxide; gamma irradiation; heat; controlled atmosphere, and combinations; inspection/detection techniques; pre-ship-

ment sanitation or inspection/certification, and biocides.

Grapes tolerate sulphur dioxide well, controlled atmosphere tolerance is poor to carbon dioxide for long term storage. Automated inspection/detection techniques for mites on grapes could be used for detection, however a treatment is needed if pests are found at arrival.

## Research Needs

### *Medium Priority, Short Term*

Test susceptibility of mites and other import pests to potential quarantine treatments.

Accelerate testing of grapes with sulphur dioxide/carbon dioxide. Information is in on tolerance of grapes to sulphur dioxide.

### *Medium Priority, Long Term*

Develop methods for automated inspection/ detection of pests(mites) on grapes.

Reinvestigate use of irradiation on grapes.

Determine feasibility of systems approaches incorporating pest-free areas and host suitability for grapes.

## CITRUS

The commodity includes grapefruit, lemon, lime, oranges, etc. These commodities are infested by a wide range of pests including fruit flies, fuller rose beetle, scale insects, and hitchhikers.

The scope of these pest problems is interstate, export, and import. Methyl bromide treatments damage quality of most citrus. Some citrus is imported after methyl bromide treatment and some interstate shipments (from Texas during Mexican fruit fly outbreaks) are also treated. Alternative treatments have been devised.

## Existing Alternatives

Fly-free zones (grapefruit, oranges), Texas, Florida; cold (Florida), hot air; vapor heat, hydrogen cyanide (scale insects); high pressure H<sub>2</sub>O (scales insects, Fuller Rose Beetle).

No alternative treatments are available for incidental or hitchhiking pests from areas that require treatment only when pests are detected. The attributes of temperature treatments and pest-free zone/period are discussed below.

## Potential Alternatives

Force vapor heat; irradiation; modified atmospheres; bioregulation of hosts; host suitability (Tahiti limes for Caribbean fruit fly); and genetic manipulation of host/pest.

Bioregulation involves inducement of non-host status by manipulation of host physiology. Genetic manipulation of host/pest will involve induced genetic changes in fruit or pest to increase resistance (fruit) or susceptibility (pest) to treatment.

## Research Needs

### *High Priority, Short Term*

Temperature treatments: continue research on fruit and pest tolerances for confirmation of additional treatments and for information leading to bioregulation and genetic manipulation approaches.

### *High Priority, Long Term*

Genetic manipulation, bioregulation.

Systems approach.

### *Medium Priority, Short Term*

Pest-free zones: continue research (mainly on fruit flies) for expansion and maintenance of pest-free zones.

## **Irradiation**

Controlled atmospheres: Continue research on fruit tolerances and pest susceptibility for storage or treatment under controlled atmospheres alone or as combinations. Test citrus using shrinkwrap films or coatings.

*Medium Priority, Long Term*

Host susceptibility, allelochemicals, and resistant varieties.

## **BERRY CROPS**

The commodity includes strawberry, raspberry, blueberry, and blackberry. The berry crops are infested by a wide range of pests, including blueberry maggot, thrips, aphids, mites, plum curculio, *Anastrepha* spp, and hitchhikers. The scope of these pest problems is interstate (blueberry maggot, plum curculio); export to Canada (blueberry) and Japan (strawberry), and imports (hitchhikers).

### **Existing Alternatives**

None for internal feeders (blueberry maggot).

Inspection/certification (for hitchhikers), but imports inspected at port of entry do not have a backup in case commodities are found to be infested.

### **Potential Alternatives**

Irradiation, Acetaldehyde (hitchhikers), controlled atmosphere, sulphur dioxide, carbon monoxide, hydrogen cyanide, heat, cold, and combination treatments.

Irradiation is used for some species of fruit flies and should be tested for other insects. Cost of irradiation is high and there are placement and operational concerns. At or above 0.5 kilogreys, irradiation may extend shelf life of product. Research is needed for testing temperature/controlled atmosphere interactions as well as varieties which

will tolerate heat or cold. Tolerance of berry crops to carbon monoxide, hydrogen cyanide, and other biocides may be limited.

## **Research Needs**

*High Priority, Short Term*

Research alternative treatments for hitchhikers and other surface pests which are identified upon arrival.

*Medium Priority, Short Term*

Tests on irradiation of berry crops for disinfestation of internal feeders.

*Medium Priority, Long Term*

Selection of varieties of berries tolerant to longer treatment times to heat and cold.

Develop biocides or controlled atmosphere treatments for berries

*Low Priority, Short Term*

Identify hitchhiker pests and determine susceptibility to potential treatments.

## **ROOT CROPS**

The commodity includes yams, sweet potato, cassava, taro, and garlic. The root crops are infested by a wide range of pests, including Curculionidae, nematodes, and surface hitchhikers. The scope of the problem is international and imports.

### **Existing Alternatives**

None for garlic and yams (which require a methyl bromide fumigation as a condition of entry), and inspection and certification for hitchhikers. As in the case for many hitchhiker pests, APHIS needs a method for treating commodities found to be infested upon inspection at port of entry.

There is no backup for methyl bromide fumigation if pests are found upon inspection/certification at port of entry.

### **Potential Alternatives**

Hot water dips, high temperature forced air, irradiation, detection, pre-shipment inspection/clearance (for hitchhiker pests).

Some irradiation research on weevils is being done in Miami and Japan to determine sterility dose. Product quality of many root crops to potential temperature treatments (high temperature forced air, dips) is unknown. Detection will aid inspection and certification of product at port of entry and could be used for developing pre-shipment inspection/clearance protocols.

### **Research Needs**

#### *High Priority, Short Term*

Develop pre-shipment sanitation, inspection/detection techniques for hitchhiker pests.

#### *Medium Priority, Short Term*

Develop alternative treatment for yams and garlic.

Dose mortality of pest weevils to irradiation and temperature treatments.

#### *Medium Priority, Long Term*

Develop systems approaches which will reduce infestation in the field and develop treatment based on actual risk.

#### *Low Priority, Short Term*

Research on basic biology of pests found on yams and garlic.

#### *Low Priority, Long Term*

Improve methods for detection of pests in root crops.

Studies on how treatments affect product quality/shelf life.

## **VEGETABLES**

The commodity includes snap beans, green pod vegetables, etc. Pests do not pose a problem as a condition of entry. Hitchhikers are a problem if product is found to be infested (bruchids, chalcids, lepidopteran pests). The scope of these problems is imports, international, and some interstate.

### **Existing Alternatives**

Inspection and certification; vapor heat is used in Japan primarily to control melon fly.

There are no alternatives for hitchhikers found in commodity imports. Inspection is labor intensive and requires sampling of most or all the commodity; however, product quality is not compromised by a treatment.

### **Potential Alternatives**

Ethyl or methyl formate or both. *Advantages:* Many biocides may have attributes similar to methyl bromide which would be ideal for treatment of commodities found to be infested upon inspection at ports of entry. Chemical treatments are generally broad spectrum and require short treatment times. *Disadvantages:* Environmental and health considerations may limit registration of many biocides. The costs involved with registration may limit the number of compounds that companies register.

Vapor heat, hot water dips (thrips), cold treatments, irradiation (snow peas and lettuce), hydrogen cyanide (surface pests), detection, pre-shipment inspection, clearance, pest-free zones, systems approach

Irradiation costs are currently high, and little data are available. Some treatments, such as hydrogen cyanide, are not registered by the manufacturer. Hydrogen cyanide will work only with surface

pests. Residue problems are unknown. Worker safety could be an issue with some alternatives.

## Research Needs

### *Medium Priority, Short Term*

Radiation dose mortality studies must be completed for all pests, especially hitchhikers. Product quality and tolerance must be determined for each pest.

Test applicability of hydrogen cyanide, irradiation, and other treatments which do not require long treatment times to kill the pests.

Test vapor heat for vegetables infested with fruit fly.

### *Medium Priority, Long Term*

Research on basic biology/physiology of the pests.

Research on product quality/shelf life.

Develop pest-free zones and systems approaches which incorporate integrated pest management approaches as well as treatments based on known risk.

### *Low Priority, Short Term*

Improve methods for detection/inspection of pests on commodities.

## MELONS, SQUASH, AND CUCUMBERS

These commodities are infested by a wide range of pests, including *Bacterocera* (spp), South America melon fly (*A. grandis*), lepidopterans, and hitchhikers. The scope of these pest problems is international and imports.

## Existing Alternatives

Fly-free zone (it is being evaluated for South America melon fly). Setting up infrastructure for

pest-free zone is time and labor intensive and difficult. It must include trapping and monitoring.

## Potential Alternatives

Hot water (for thrips, fruit flies), hot forced air, vapor heat, host status and fly-free for systems approach, irradiation, combination treatment, acetaldehyde (for surface hitchhikers), shrinkwrap, films-coating.

Shelf life extension and product quality for many potential treatments are unknown. Temperature limits for hot water treatment of *Bacterocera* are fairly well known. Vapor heat equipment is available in Hawaii. Irradiation dose needed for sterility in fruit fly is known. Shrinkwrap films may help prevent reinfestation and extend shelf life in some fruits.

## Research Needs

### *High Priority, Short Term*

Complete tests on heat treatments of commodities against fruit flies.

Continue product quality evaluations in conjunction with any potential treatment.

Treatment for hitchhikers identified at port of entry/inspection.

### *Medium Priority, Short Term*

Further tests on use of irradiation.

### *High Priority, Long Term*

A systems approach incorporating the fly-free zone concept must have suitable packing and inspection programs. Research to allow field packing of the commodity may be better than transporting the product to the insect-free packing area.

### *Medium Priority, Long Term*

Test shrinkwrap films and coatings for effectiveness in disinfestation of commodities.

Develop detection systems for use in systems approaches and for hitchhikers.

## **BANANA, PLANTAIN, AND PINEAPPLES**

These commodities are infested by a wide range of pests, including external feeders, lepidopterans, mites, thrips, hitchhikers, and fruit flies. The scope of these problems is imports. Methyl bromide is used if pests are found upon inspection.

### **Existing Alternatives**

Inspection/certification, pre-shipment inspection/clearance. Pre-shipment inspection /clearance will lessen the threat of pests arriving at port of entry; however, a backup is still needed if pests are found at arrival.

### **Potential Alternatives**

Hot water (for fruit fly), controlled atmosphere, biocides, host status, irradiation, detection. Hot water dips have been shown to be effective on bananas for some species of fruit flies (internal feeders) and may also be useful for external feeders. Size of treatment facility for large shipments may be a problem. Treatments which will control a wide variety of pest species and require only short treatment times are preferred attributes for situations where pests are found at inspection. Controlled atmosphere may be useful if in-transit methods for treatment could be worked out.

### **Research Needs**

Although the short-term view for most of the cases in which pests are found upon arrival is that another effective, quick-acting biocide is needed, the longer term view held by many participants is that biocides will continue to be under regulatory scrutiny and that long-term research on reducing risk of entry of exotic pests is needed.

### *High Priority, Short Term*

Develop standard method(s) to measure what constitutes kill for irradiation treatments.

### *High Priority, Long Term*

Develop disinfestation procedures using temperature, controlled atmosphere, and other direct treatments.

### *Medium Priority, Short Term*

Identify pests which are most frequently found and for which a treatment is needed for the commodities in question. More information on the basic biology of these pests is needed if we are to develop methods to control them.

Conduct preliminary dose/mortality tests on pests using proposed treatments.

Develop pre-shipment sanitation, inspection/certification protocols which would reduce the chance that pests would be found upon arrival. Improve pre-shipment sanitation.

### *Medium Priority, Long Term*

Develop systems approaches for long-term risk analysis.

### *Low Priority, Long Term*

Develop resistant crop varieties.

## **AVOCADO**

This commodity is infested by a few pests including fruit fly in Hawaii (could also be a problem with other fruit flies, weevils and other pests in Mexican avocados). The scope of these pest problems is national (imports to mainland), local, interstate, regional, and exports.

**Existing Alternatives - None**

## Potential Alternatives

Fly-free zone, host status, resistant varieties, cold treatment, heat treatment, irradiation (var. dependent), irradiation with inert atmosphere.

Irradiation of avocados causes fruit damage in some cases. Future development of irradiation for avocado may be variety specific. Cold treatment will be cultivar dependent. Seasonal variability in growing areas may be a problem. Risk analysis needs to be set up for fly-free, host status, and resistant varieties.

## Research Needs

### *High Priority, Short Term*

Cold treatment of Hawaiian avocado should be pursued first. A heat treatment may also work with some modification.

### *Medium Priority, Short Term*

Test irradiation on other commercial cultivars (may not work with Hawaiian cultivars).

### *Medium Priority, Long Term*

Develop pest/host information which could be used in development of systems approaches or fly-free zones for avocado.

Identify cultivars which may be resistant to infestation and the conditions under which these occur.

## GENERAL ATTRIBUTES AND RESEARCHABLE ISSUES RELATED TO MAJOR ALTERNATIVE TREATMENT GROUPS

Several treatments were identified as existing or potential alternatives for use with several of the commodity groups. Most of these treatments are being addressed in active research programs carried out by the participating scientists. Industry and regulatory representatives also had a number of

comments and questions concerning both the status of these treatments and their use. Groups are classified in the general system used by ARS laboratories conducting post-harvest research. These groupings include temperature treatments, modified/controlled atmospheres, biocidal agents (mainly alternative fumigants), irradiation, pest-free zones, clarification or modification of host status and suitability (including pest-free periods, screening for susceptibility, bioengineering, and treatments to increase resistance), and various combinations of the above treatments or development of systems of treatments that reduce risk of infestation to acceptable levels.

The attributes and issues identified for these treatments emphasize these aspects that seemed to be important for a wide variety of commodities. In this discussion it should be noted that combinations of nearly all these treatment groups have been proposed for at least some commodities. Emphasis was on single treatments or processes; however, combination treatments and systems approaches were considered high priority for the long term. Other long term solutions, such as pest eradication, should also be considered. The emphasis on simplest and likely to be rapidly adapted treatments reflects the urgency to develop suitable alternatives.

### **Cold treatments:**

**Product Quality:** Temperate fruits, in general, appeared to have more potential than tropical fruits, citrus being a major exception. Preharvest field conditions, seasonal differences, varietal differences, and a number of other factors were identified as factors needing better understanding in order to optimize product quality when cold storage is used for product disinfection. A major advantage of cold storage relative to product quality is extension of shelf life (as opposed to heat which may shorten it). With improvements in engineering of refrigeration systems, some products may be stored at significantly colder temperatures ( $-0.5^{\circ}\text{C}$ ) than previous reports may indicate if soluble solids are high.

**Pest Issues:** Some pests will require long treatment periods. For example: codling moth eggs in apples will require more than 30 days storage and larvae more than 3 months. Research needed for many insects include better predictive methods to determine life stage specific tolerances, understanding of natural variation among populations and closely related species, and the effects of rearing conditions and laboratory adaptation on insects used for experiments. Cold storage apparently does not always reduce risk of surviving hitchhikers or incidental pests.

### **Heat treatments:**

**Product Quality:** Heat tolerances for many commodities are poorly understood. Determination of the best heating methods (water, vapor, forced air), maximum temperature and time combinations, and heat transfer characteristics must be made to develop heat disinfestation treatments. Other factors that must be determined include conditioning pretreatments to increase commodity tolerance, and post-treatment handling and storage methods to optimize shelf life and overall quality. This is especially true for temperate fruits (pomes, stone fruits). Effects of heat treatments on the microorganism community on the fruit surface and the possible increase in disease susceptibility also require further study.

**Pest Issues:** A large amount of information concerning pest tolerances to heat has been developed over the last 10 years, especially for tropical fruit flies. Active research programs on important quarantine pests for pome fruits and stone fruits are being pursued. Efforts to better understand variation in susceptibility for various life stages and other sources of variation are needed (as in the cold treatments) for many of the pests including those that have received attention.

### **Biocides:**

**Product Issues:** Regulatory members of our group noted the extreme diversity of products that require treatment for hitchhiking pests and pests that require treatment only when detected at ports of

entry. These products presently require treatments when a pest is detected even for commodities that may have received a treatment before export. They estimated that up to 40% of some commodity shipments, such as pineapple, require treatment for hitchhikers. Other fruit, such as bananas, requires treatments for huge volumes when whole shiploads of fruit must be treated. Treatments that require extensive additional knowledge of commodity tolerance may be impossible when coupled with the need for extensive knowledge of the pest tolerance. Chemical agents that may have marginal use for internal pests, such as larvae, may hold promise for this class of pests.

**Pest Issues:** The hitchhiker list of pests includes over 200 species. As is the case with the commodities, the research effort required to find lethal treatments for each of these species would be considerable. While there is some possibility of grouping pests according to expected tolerances or treatments, a chemical treatment for external pests would have great value when these pests are detected. A list of chemicals that have potential for registration needs to be compiled. The group suggested a number of examples of chemicals that may have potential for this use.

### **Controlled atmospheres**

**Product Issues:** The use of controlled atmospheres in conjunction with cold storage has long been used for temperate fruits and vegetables. High temperatures for short duration have been shown to be effective against certain external pests (New Zealand, Australia). Overall, however, little is known about the tolerances of commodities (temperate or tropical) for controlled atmosphere treatments or combinations with temperatures that are insecticidal. Temperate products may be more amenable to controlled atmosphere treatments than tropical products.

**Pest Issues:** Most reports of successful treatments using controlled atmospheres have involved external pests, especially mites. Attempts to use fruit coatings or shrinkwraps have shown promise to reduce infestation but have not been effective to

reach quarantine security as single treatments. These wraps or coatings may have to be removed so the product can respire after the treatment period. Internal pests, especially fruit flies and lepidoptera, have been evaluated for these treatments.

### **Irradiation:**

**Product Issues:** The primary issue raised for product quality was that there is extensive literature on effects of radiation on quality but given the wide variety of types of studies, equipment and methods used, and the often incomplete descriptions of the methods, much of the data and conclusions are conflicting among reports. A large number of commercial-scale tests have been carried out for several commodities for evaluation of quality. For a number of commodities, the information on shelf life and storage methods is lacking. Probably the most important issue was whether separate data would be necessary for certification for each pest/commodity combination or whether mortality for a pest species would be the same over all commodities.

**Pest Issues:** There was considerable discussion concerning the criteria for effective treatment, in particular, the issue of reproductively sterile and possibly severely impaired but still living pests in commodities. The issue of possible variability among different populations of pests, especially when the literature shows different dose requirements for different populations (possibly due to variable experimental methods) also needs to be clarified. An important priority should be to establish the requirements for submitting data and protocols for approval from regulatory agencies. The need for experimental data that provide estimates of risk as well as confirmatory data was discussed.

### **Pest-free zones:**

**Product Issues:** Geographic areas where commodities may be produced and exported due to the absence of quarantined pests have been recognized in a few instances. The characteristics of these

zones may vary but generally the zones must be isolated and products entering the zones are subject to quarantine. This requires an internal quarantine in some countries. Enforcement and monitoring are major issues in maintenance of these zones. In some cases, certification may be lost if pest outbreaks occur. Shipping windows may be necessary in cases when there are periodic outbreaks.

**Pest Issues:** Extensive knowledge of the pest biology is needed to establish detection and internal quarantine systems. This includes attractant and trap development as well as knowledge of host range. Several pest-free zones are maintained by sterile insect release programs that further require ability to rear, sterilize, and disperse effective insects. Knowledge of the biogeography and environmental tolerances of the pest is also essential.

### **Host suitability**

**Product Issues:** A number of approaches to host suitability, identification, and possible modification were discussed. Update and correcting host lists for pests is an ongoing effort. Identifying variety characteristics of a number of fruits (plums) that reduce or preclude their use as hosts by certain pests appears to be promising for some markets. Modifying fruit by certain treatments such as growth hormones may be effective for some citrus against some fruit flies. Genetic modifications by conventional breeding methods or bioengineering have already been developed that may affect ripening characteristics that are associated with oviposition requirements or larval feeding.

**Pest Issues:** Genetic alterations to change host status require knowledge of the factors that preclude host use. Peel characteristics, nutrients, and possible chemical protective compounds must be identified for modification. The wide variety of environmental factors including pest population density, availability of alternate hosts, physiological condition of the host, and phenological variability adds to the complexity of host suitability evaluations.

## Systems approaches

**Product Issues:** Systems approaches have much promise in development of future quarantine treatments. The systems approach depends on improved knowledge of the pest population levels in the field as well as how various pre- and post-harvest practices can affect the numbers of pests in the commodity. Using incremental reduction practices based on known population levels, a more realistic assessment of risk, and the need for subsequent treatment can be determined.

**Pest Issues:** In many cases, it has been recognized that not all hosts are infested to the same degree. Fruits and vegetables which are poor or marginal hosts may not need quarantine treatments which are as severe as those of good hosts. Overall quarantine risk must include information on the pest population in the field.

## SUMMARY OF RESEARCH NEEDS

The major quarantine issues for fresh fruits and vegetables are: lack of suitable alternative treatments for export of temperate tree fruits (pome fruits and stone fruits) and citrus; lack of treatments for the large number of hitchhiking pests that may be found on commodities; lack of information on the effects of potential treatments on product quality and shelf life; and lack of treatments for numerous imported fruits and vegetables. Pome fruit pest problems include codling moth and lesser apple worm. Heat treatment, cold treatment, and possible controlled atmosphere storage may present short-term (less than 7 years) solutions for some export markets. Alternative treatments for stone fruits may present more serious short-term problems due to sensitivity of fruit to treatments. However, heat tolerance research is in progress for several stone fruit varieties and their pests. Research on codling moth tolerances to heat and cold will be applicable to stone fruits; however, pest issues such as oriental fruit moth, walnut husk fly, and other pests may need investigation. Intra-state shipments (from Eastern United States to California) of some stone fruits will require treatment for plum curculio. Possible alternative treatments for

some stone fruits include demonstration of non-host status (some plum cultivars), pest-free periods (plums and nectarines), and security through systems approach (cherries, nectarines). Because of the high value of these commodities, research to complete confirmation of these approaches should be given high priority.

Several alternative treatments are already approved for citrus. The major issue for the temperature treatments of the three major citrus commodities (tangerines, grapefruit, oranges) is product quality. Research to fine-tune the treatment times and temperatures to produce treatments that may produce better quality with respect to geographic, seasonal, varietal, and marketing factors needs to be carried out. Cooperation between plant physiologists, plant pathologists, and entomologists is needed to do this research. Pathology issues related to microorganism ecology under various temperature stresses must be resolved for several citrus species.

The use of irradiation as a quarantine treatment should be reviewed for grapes and berry commodities that are known to be intolerant of heat or are so perishable that any accelerated ripening would be detrimental. A review of possible alternative biocides such as hydrogen cyanide, and testing of new combinations of temperature with controlled atmosphere, may resolve some problems of external pests on these commodities.

Research concerned with harvest technology, especially field packing practices, may be useful for removing some hitchhiker pests. Pre-shipment sanitation and treatments such as washing, better inspection/culling systems, and other processing practices could reduce the incidence external pests that require treatment when encountered at ports of entry. Root crops, vegetables, bananas, pineapples, and some cucurbit crops are frequently treated with methyl bromide when external pests are detected.

Fruit flies in the Pacific, Asia, and Central and South America may restrict import of melons from these areas. Heat treatment research is required to

determine the tolerances of the pests (South America) and the commodities. Similarly, fruit flies in Hawaii and Mexico prevent the export of avocados (methyl bromide is registered but not used for these pests due to phytotoxicity caused by the treatment). Cold treatment research needs to be completed for Hawaiian avocados and may be applicable for Mexican varieties.

Many of the above issues are amenable to more indirect approaches such as establishing or modifying non-host status of the commodities. Pest-free zones are presently used for many quarantine pests. Research into basic biology of a number of pests has been very beneficial in establishing pest-free zones for fruit flies in Florida and Texas and maintaining the citrus production areas of California free of fruit flies. Research is needed to extend our knowledge of potential invaders, especially the fruit fly species-rich genera *Bactrocera* and *Anastrepha* will aid in preventing their introduction into fruit and vegetable production areas in the United States and their eradication, should they be introduced.

### Research Approaches:

Historically, the research approaches used in development of quarantine treatments have been largely empirical using broad spectrum toxicants. The loss of ethylene dibromide (EDB) and the current pending loss of methyl bromide has required researchers to rethink conventional paradigms in the development of new alternatives. A significant commitment to basic knowledge on the physiology of the pests as well as the fruit to non-chemical treatments such as heat has resulted in successful development of alternative treatments. These are discussed as issues relative to product quality and pest issues for each treatment. The approaches are closely tied to both commodity and pest for the research approaches discussed here. Irradiation research relative to quarantine issues is being compiled by international agencies (Food and Agricultural Organization, International Atomic Energy Agency) and needed research will be identified from these reports.

### Research Priorities:

The overall research priorities are given in approximate order of priority. Prioritization was based largely on approaches and alternative treatments that have been successfully developed for commodities such as mangoes, citrus, apples, and papayas. Many fruit industry representatives agreed that treatments as similar to methyl bromide as possible should have priority. The lack of approved fumigants and the lengthy time periods required for approval and registration of new chemicals, along with the relatively limited use in quarantine expected for many commodities, reduced the priority of research in this direction.

The following research approaches and priorities were identified to provide maximum short and long-term solutions and benefits:

Research to determine the relative susceptibility and tolerance of pests at different life stages in or on different host commodities, or to existing or potential treatments.

Research to determine commodity tolerance to above treatments with respect to product quality and shelf life, and to the packing-distribution-marketing systems.

Research to develop (short term) alternative bio-cidal treatments and to improve inspection and packing systems to eliminate hitchhiking pests at ports of entry.

Research on fundamental knowledge of pest biology, behavior, ecology, and physiology relative to host status, host resistance, and systems approaches (including pest-free zones) to provide quarantine security.

Research to develop methods for estimating the risks involved with introduction of quarantine pests for systems approaches, especially relative to host and pest variability, and potential for establishment if pests are introduced.

## Session III: Grains and Milled Products

Discussion Group: *Chairs*, James Leesch & William McGaughey; *Members*, Frank Arthur, John Brower, James Coffelt, Robert Cogburn, Gerrit Cuperus, Florence Dunkel, Paul Flinn, Jim Fons, Patrick Gomez, Ed Jay, Karl Kramer, Dirk Maier, David Sauer, Dennis Shuman, Noel White

### INTRODUCTION

Fumigation of grains and milling products with methyl bromide has been an important means of limiting the loss of quality and quantity of these commodities that are subject to attack by cosmopolitan stored grain pests. In addition, methyl bromide is used for occasional quarantine treatment of grain shipments and routine treatment of burlap packaging as a condition for import of these products to prevent entry of khapra beetle into the United States. For any substitute to be acceptable, it must possess the following desirable attributes: fast kill of insects; no adverse impact on quality of commodity; no residue; easy to use; and cost effective. The attributes of two existing (phosphine fumigant and controlled atmosphere) and several potential alternatives (residual chemicals, inert dust, insect pathogens, sanitation, improved monitoring, novel chemicals, irradiation, parasites/predators, behavior disruption, heat, hydrogen cyanide, chloropicrin, biotechnological approaches, space and residual treatments, system approaches, and aeration/chilling) were discussed. Based on the current knowledge, most of these alternatives have researchable gaps or other constraints. Additional research is needed to evaluate their effectiveness as acceptable alternatives to methyl bromide. None of these alternatives used alone will replace methyl bromide. Successful pest control in the absence of methyl bromide will require the development of sophisticated pest monitoring and decision support systems (expert systems) to enable the use of integrated pest management strategies.

The alternatives to methyl bromide are discussed in four application groups based on the current use of methyl bromide to solve the pest problems associated with these commodity/quarantine categories. These include: unprocessed grain; processed dry edible products; milling and processing structures; and quarantine treatment (for khapra beetle).

### COMMODITIES, PEST PROBLEMS, AND SCOPE:

#### UNPROCESSED GRAIN

The commodities include wheat, rice, corn, soybean, barley, oat, etc., and are attacked by cosmopolitan stored product pests. The problem is national in scope. It was estimated that as high as 5% of the commodity/quarantine use of methyl bromide occurs in this category.

#### Existing Alternatives

*Phosphine*: Phosphine fumigant is already used on about 73% of unprocessed grain. The *advantages* include: ready availability; ease of application; efficacy; and without residue. The *disadvantages* include: concern over environmental and health hazards, including possible chromosomal aberrations in users; evidence of pest resistance; need for 3- to 5-day treatment is too long where quick turnover is required; and laws which limit the release of phosphine into the atmosphere.

*Controlled Atmosphere (nitrogen, carbon dioxide, "burner gas")*: Based on available data for many grains, the *advantages* include: ready availability; highly efficacious; safe for environment and health; and exempt from a tolerance level. The *disadvantages* include: requires long treatment time (4-21 days depending on temperature and carbon dioxide (or low oxygen with nitrogen) concentrations); is more effective in vertical than in flat/horizontal storage; requires better sealing than methyl bro-

mide; has possible adverse effect on new concrete; and may create excessive pressures on side walls.

## Other Feasible Alternatives

*Residual Chemicals:* These can be used only for protection, not for disinfestation. The *advantages* include: ease of application; long-term protection against infestation; ready availability of some chemicals such as Actellic® and Reldan®; and minimal cost. The *disadvantages* include: residues unacceptable to milling industry; lack of consistent broad spectrum efficacy; little incentive for industry to develop new residual chemicals due to high cost and long time required for registration; and development of resistance to the pesticides by insects.

*Inert Dusts:* These can be used only for protection, not for disinfestation. The *advantages* include: ease of application; long life in grain storage; and few environmental concerns. The *disadvantages* include: undesirable effects on handling characteristics of grain; possibility of damage to equipment due to residue carryover to milling process; and possible adverse effects of dusts on workers.

*Microbials (insect pathogens):* These can be used only for protection, not for disinfestation. The *advantages* include: availability of agents such as *Bacillus thuringiensis* and granulosis virus; ease of application; cost effectiveness; lack of toxicity to humans with no danger to health or environment; harmless to parasites and predatory insects; and lack of harmful residues. The *disadvantages* include: lack of efficacy against all pest species; potential for resistance by insects; slow acting; lack of efficacy data for some potential uses; and possible negative public perception.

*Aeration/Chilling:* These can be used only for protection, not for disinfestation. Much data already exists about aeration in the United States and chilling systems are being used in Europe. The limited amount of research needed should be given a high priority, so that general use of this technology can be achieved. The *advantages* include: availability of technology; ease of use, once equip-

ment is in place; high efficacy on corn, rice, wheat, and popcorn; and chilling equipment can be mobile. The *disadvantages* include: using refrigeration for chilling has higher cost than methyl bromide; and aeration using ambient air may not be as useful in southern or southeastern regions of the country.

*Sanitation:* This approach is an essential component of all strategies, but its value is poorly documented. The *advantages* include: elimination of insect harborage and food; safe for environment and health; and eliminates or reduces need for other treatments. The *disadvantages* include: highly time consuming; need for continuous maintenance; and difficulty in cleaning certain areas/machinery.

*Monitoring:* This technology includes probe traps, hanging traps - with or without pheromones, ELISA tests, and acoustic methods for detecting insects. The *advantages* include: early warning of pest infestation problem and its severity; elimination of unnecessary “scheduled” insect treatments by efficient monitoring; and applicability in a variety of storage situation. The *disadvantages* include: difficulty in correlating trap catch to population size; inability to locate site of infestation; and time and record-keeping intensive.

*Insect growth regulators, chitin inhibitors, hormone mimics:* These can be used only for protection, not for disinfestation. The *advantages* include: availability of some broad-spectrum registered chemicals (methoprene); and low mammalian toxicity. The *disadvantages* include: residues in finished products unacceptable to milling industry and consumers groups; slow acting allowing the most destructive stage, larvae, to feed on commodity before killing the pest insects; sometimes does not control all species; and expensive.

*Irradiation:* This technology provides an alternative to methyl bromide. Little or no research is needed to use this technology now.

The *advantages* include: very effective method of disinfestation; technology ready with considerable data in place; and ease of use once the equipment is in place. The *disadvantages* include: unfavorable public perception of irradiation; high cost of moving

grain to the equipment; and the high cost of initial installation.

### **Potential Alternatives (Short Term)**

*Expert Systems:* Decision support systems are a fundamental part of future pest management systems. *Advantages:* Alternative pest control technologies are not always highly effective, broadly applicable, inexpensive, or easily used. They require extensive knowledge and skill to use effectively. Computer-based decision support systems are necessary to interpret complex environmental and commodity situations and to select cost-effective control measures. Expert systems have been adopted for decision support in other complex control areas. These systems are based on models of insect population dynamics and responses to environmental conditions and control measures which allow the integration of control systems. There is *no disadvantage* in using expert systems.

*Parasites/Predators:* Biological control by parasites and predators can be used only for protection and not for disinfection purposes. The *advantages* include: environmentally safe and without health hazards; and compatibility with other nonchemical systems. The *disadvantages* include: comparatively costly at the initial stages; lack of adequate field data; need to use before pest population grows; possible regulatory constraints, if insect fragment counts increase as a result of releasing parasites in the grain; and parasites/predators are not available for all pest species.

*Pheromones/Behavior disrupting chemicals:* This technique has promise for future application, but the research investment will be great and the benefits will not be immediate. The *advantages* include: compatibility with other forms of biological control; and promising results in some cases from small scale experiments. The *disadvantages* include: lack of availability of pheromones for all pest species; effective mating disruption occurs only at low population densities; effectiveness of

mass trapping has been inconclusive; and pest activity will not be completely eliminated in the facility/grain.

### **Potential Alternatives (Long term)**

*Biotechnology (host plant resistance and biological control improvement):* This is a highly desirable technology that requires extensive research investment. Development will be driven primarily by progress in crop production systems. Currently, interest is focused on enhancement of proteins and peptides that affect the insect gut (Bt toxin, immunoproteins, antinutritional proteins, gut enzyme inhibitors). A second promising approach involves enhancement of insect pathogenic virus effectiveness using chitinase, juvenile hormone (JH) esterases, scorpion toxins, mite toxins, and *Bacillus thuringiensis* (Bt) toxins. The *advantages* include: continuous protection of commodity by enhancement of host plant resistance; and improvement in efficacy of environmentally safe biological control agents. The *disadvantages* include: potential problem of consumer acceptance; regulatory constraints; and potential pest resistance.

*New Fumigants:* The development of new, acceptable fumigant materials is unlikely, given the current consumer concern over the quality of the environment. However, some new and previously investigated compounds may be developed as alternatives. Since fumigants must be highly volatile (and therefore of low molecular weight), most candidate compounds have been investigated previously.

*Insect growth regulators:* It is expected that future research will open the way to significant improvements and additional uses for these technologies in controlling stored grain insects.

### **Research Needs and Priorities for Unprocessed Grain**

#### *High Priority, Short Term*

**Controlled Atmospheres:** Research is needed on: combinations of low oxygen atmospheres with high temperatures; membrane production of nitrogen atmospheres; and development of improved sealing techniques.

**Aeration/Chilling:** Aeration technology needs little research. The primary need is to develop recommendations and define limitations for different climatic conditions and encourage adoption. Research is needed on the use of refrigeration for chilling to develop methods to avoid moisture problems in commodities and to develop and adapt systems to diverse storage situations.

**Monitoring:** Monitoring systems are essential to all pest control systems. Research is needed to: develop efficient methods to relate trap catches to actual population density; automate data reporting; develop more traps for a broad range of pest species; and perfect the use of acoustic monitoring for bulk grain storages.

#### *High Priority, Long Term*

**Monitoring:** Research on monitoring is expected to yield significant short-term benefits, but additional significant improvements will result from longer term research, particularly in the areas of automated data collection, acoustic monitoring, and coupling of monitoring systems with decision support systems.

**Expert Systems:** Decision support systems, along with monitoring, provide the foundation for integrated pest management systems and will be essential to the success of most of the alternatives being considered. An expert system has been developed for farm-stored wheat and is being field tested. Extensive refinement and augmentation of the rule base is needed to adapt this system to other commodities and storage situations and to include a wider range of insect control options. Significant effort will be required to model the effects of environmental parameters and various insect control approaches. Validation of expert systems will require a major long-term effort.

#### *Medium Priority, Short Term*

**Sanitation:** The benefits of sanitation are well known. Research is needed to quantify the benefits of specific measures and develop models for use in integrated pest management systems. These models can be incorporated in expert systems described above.

**Insect growth regulators, chitin inhibitors, hormone mimics:** While several of these chemicals are available for use now, research is needed to discover compounds that control a wider range of pest species to: develop techniques for their effective use; deal with residues in commodities; and lower their cost. In addition, chemicals which kill early-larval stages (most destructive stage in most stored products) are needed.

#### *Medium Priority, Long Term*

**Parasites/Predators:** Research is needed to: discover parasites/predators for a wider range of pest species; field-test these agents under actual storage conditions on different grains; and show the benefits of this biocontrol combined with other techniques.

**Insect Pathogens:** Pathogens for lepidopteran pests of commodities are currently available (*Bacillus thuringiensis* and granulosis virus). However, research is needed to discover and evaluate pathogens for coleopteran pests.

**Pheromones/Behavior Disruption:** Before this technology can be used, research is needed to: find pheromones for a wider range of pest species and develop operational techniques for field use. More research is needed on how to use pheromones to disrupt insect mating in head spaces over commodity storage.

**Insect growth regulators, chitin inhibitors, hormone mimics:** While short-term research will achieve some desirable benefits from this technology, longer term research will be needed for full development. Compounds which give a quick kill of

larvae (most destructive stage) must be found and developed.

Biotechnology (host plant resistance and biological control improvement): Research has already demonstrated the feasibility of gene transfer techniques in enhancing host plant resistance and the effectiveness of biological control agents. An extensive, long-term research commitment is needed to bring this technology to adoption.

#### *Low Priority, Short Term*

Phosphine: Research is needed to improve application and aeration techniques for large grain bulks and investigate the usefulness of combining phosphine with controlled atmospheres or high temperatures, or both.

Residual Chemicals: Several residual chemicals are available for use now. The need for extensive research is not anticipated because residues in commodities make the use of these materials undesirable. However, protectants may still play a major role as an alternative as other technologies are developed and combined into a useful integrated pest management plan.

Inert Dusts: Some inert dusts are available for use now. Research is needed to develop formulations that are effective at lower doses and are acceptable by processors and consumers. Some inert dusts are of little value in suppressing insects. New dusts, not damaging to milling equipment, are needed.

#### *Low Priority, Long Term*

New Fumigants: The development of new, acceptable fumigants is unlikely and would require extensive research. Reinvestigating potential fumigants may be useful in replacing methyl bromide.

## **PROCESSED DRY EDIBLE PRODUCTS**

These commodities are infested by a wide range of cosmopolitan stored product pests. The scope of these pest problems is national (currently accounts

for approximately 5% of postharvest methyl bromide use). Important characteristics required for alternatives to methyl bromide include: fast kill of insects; no quality degradation; no residues; easy to use; and minimum cost.

### **Existing Alternatives**

*Phosphine*: Phosphine fumigant is already in use for disinfestation in unprocessed grain. The *advantages* include: effective penetration into many types of plastic films used in packages; readily available; ease of application, efficacy; and without residue. The *disadvantages* include: concern over environmental and health hazards, including possible chromosomal aberrations in users; evidence of pest resistance; 3- to 5-day treatment is too long where quick turnover is required; laws which limit the release of phosphine; and lack of adequate data on penetration of some packaging material.

*Controlled Atmosphere (nitrogen, carbon dioxide, "burner gas")*: Based on available data on disinfestation for many edible products, the *advantages* include: readily available; efficacious; environmentally safe; and exempt from a tolerance level. The *disadvantages* include: requires long treatment time (from 4-21 days depending on temperature and carbon dioxide (or low oxygen with nitrogen) concentrations); is more effective in vertical than in flat/horizontal storage; requires better sealing than methyl bromide; has possible adverse effect on new concrete; may create excessive pressures on side walls; and possible problems in penetration of the films used in packages.

*Irradiation*: The *advantages* include: very effective method of disinfestation; technology is ready with considerable data in place; and easy to use once the equipment is in place. The *disadvantages* include: unfavorable public perception; high cost of moving grain to the equipment; and the high cost of initial installation.

### **Other Feasible Alternatives**

*Packaging*: Suitable changes in packaging technology can greatly improve the protection (not

disinfestation) of the commodity. The *advantages* include: easily adaptable to storage condition; reduces need for chemicals; and easily tailored to the product. The *disadvantages* include: concealment of hidden population; and may be a barrier to gaseous insect disinfestation treatments.

*Sanitation:* The *advantages* include: elimination of insect harborages and food; safe for environment and health; and eliminates or reduces need for other treatments. The *disadvantages* include: highly time consuming; need for continuous maintenance; and difficulty in cleaning certain areas/machinery.

*Monitoring:* *Advantages* include: early warning of pest infestation problem and its severity; elimination of unnecessary “scheduled” insect treatments by efficient monitoring; and applicability in a variety of storage situation. *Disadvantages* include: difficulty in detection of pests inside the packages; and economic loss resulting from discarding of commodity, once the pests are detected.

### **Potential Alternatives (Short Term)**

*Packaging:* Additional research should yield applications for insect resistant packaging beyond those currently available.

*Low Temperature:* The advantages include: existence of established uses in quarantine treatment which demonstrate usefulness; little or no product damage; and especially advantageous for continuous storage where natural cooling is possible. The *disadvantages* include: higher energy requirement than heat for disinfestation treatment; greater time requirement than heat, and slow penetration into commodity.

### **Potential Alternatives (Long-term)**

*Expert Systems:* *Advantages:* Alternative pest control technologies are not always highly effective, broadly applicable, inexpensive, or easily used. They require extensive knowledge and skill to use effectively. Computer-based decision support systems are necessary to interpret complex environmental and commodity situations and to

select cost effective control measures. Expert systems have been adopted for decision support in other complex control areas. These systems are based on models of insect population dynamics and responses to environmental conditions and control measures which allow the integration of control systems. *Disadvantage* are that expert systems are not fool-proof.

*Biotechnology / host plant resistance:* The *advantages* include: continuous protection of commodity by enhancement of host plant resistance; and improvement in efficacy of environmentally safe biological control by enhancement of the biocontrol agents. The *disadvantages* include: potential problem of consumer acceptance; regulatory constraints; and potential pest resistance.

## **Research Needs and Priorities for Processed Dry Edible Products**

### *High Priority, Short Term*

*Monitoring:* Monitoring systems are essential components of all pest control programs. Research is needed to: develop methods to detect low-density infestations, especially in packages and to develop methods to interpret trap catch and acoustic data.

### *High Priority, Long Term*

*Monitoring:* Short-term research should produce significant improvements in monitoring systems. However, longer term efforts are needed to develop automated systems and to couple monitoring programs with decision support systems (expert systems).

*Expert Systems:* Decisions support systems, along with monitoring, provide the foundation for integrated pest management systems and will be essential to the success of most of the alternatives being considered. A long-term research investment is needed to develop such systems for processed commodities.

### *Medium Priority, Short Term - None*

### *Medium Priority, Long Term*

Biotechnology (host plant resistance and biocontrol improvement): Extensive long-term research is needed to apply these promising new technologies to processed cereal products. The feasibility of insect pests developing resistance to introduced genetically manipulated strains is unknown and needs long-term research.

### *Low Priority, Short Term*

Phosphine: Phosphine is already an acceptable fumigant for many processed cereal products, but research is needed on penetration into various packaging materials.

Controlled Atmospheres: Data are available on the use of modified atmospheres on packaged commodities. Research is needed on penetration into various packaging materials and development of operational procedures for various handling systems.

Packaging: Research is needed to: develop new materials which are better barriers to insect penetration, or which are barriers to commodity odors that attract insects; improve sealing of packaging; and to study the permeability of packaging materials to fumigants.

Sanitation: The value of sanitation is well established in the industry. Research is needed to: develop methods to identify sources of infestation; document the benefits of various sanitation procedures in limiting infestation of packaged commodities; and improve the design of warehouses and handling equipment.

### *Low Priority, Long Term*

Low Temperatures: Little research is needed, but widespread implementation of this technology is a long-term solution because of its high cost. Some research is needed on the rate of temperature reduction which would be the most efficacious.

## **MILLING AND PROCESSING STRUCTURES**

The commodities include flour, rice, corn, pet food, pasta, bakeries, food processors, warehouses, etc., that are infested by cosmopolitan stored-product insect pests. The scope of these pest problems is national. Approximately 75- 80% of methyl bromide used in the grain and dry food industries is for facility treatment. The facilities average four treatments per year.

Alternatives to methyl bromide should possess the following characteristics: low cost because of large space to be treated; good penetration into various machinery and structural components; no damage to structures and equipment; effective within a 48-hour time frame; and adaptable for use in a wide range of structural situations (wood, metal, concrete, multi-level).

### **Existing Alternatives**

*Controlled Atmosphere (nitrogen, carbon dioxide, "burner gas")*: Based on available data for many grains, the *advantages* include: current use in grain and some structures; available data on susceptibility of insects; current limited use of carbon dioxide at 110° F in a 48-hour time frame; and registration problems not anticipated. The *disadvantages* include: high cost of treating facilities; difficulty of maintaining concentrations in open spaces of facilities; possibility of stratification of carbon dioxide in multi-level facilities; and requirement of tight sealing, especially for nitrogen because of need to maintain 99% concentration.

*Heat*: The *advantages* include: currently widely used in industry; effective in a variety of structures; adequate penetration into machinery; cost effective; applicable as a spot/zone treatment; effective in a 48-hour time frame; non-toxic; and safe to workers. The *disadvantages* include: possible damage to heat-sensitive machinery, products, or structures; requirement of heat sources, circulation fans, and some retrofitting of structures (high temperature sprinklers); and may not be applicable in structures made of wood, sheet metal, or prestressed concrete

(approximately 20-35% of facilities) due to expansion differences of structural materials.

*Phosphine:* The *advantages* are same as discussed above for grains. The *disadvantages* include: too corrosive for this use; too costly; slow; and difficult to contain for this use.

### **Other Feasible Alternatives**

*Sanitation:* Sanitation is a well-established procedure in the industry. Its use is driven by the need (and expectation) for residue-free food. “Select Supplier” programs are being recognized as important elements in eliminating pest problems.

Although efficacy of this alternative is difficult to quantify, it promises to be useful in all circumstances. The *advantages* include: potential for reduction or elimination of need for fumigation or other controls; and elimination or reduction of pesticide residues/exposures. The *disadvantages* include: costly in terms of labor and lost productivity; difficulty in cleaning certain facilities and equipment because of their poor design; and inability to completely eliminate the problem.

*Crack/Crevise treatments:* The *advantages* include: availability of chemicals currently registered and used effectively for this purpose (pyrethroids, dursban, diazinon, ficam, dichlorovos and others); reduction of insect activity and need for fumigation; and little or no risk of contaminating commodity. The *disadvantages* include: not usable during production; failure to completely eliminate problems; and possibility of developing pest resistance.

*Monitoring:* The technology advantages and disadvantages are discussed above in dry edible products.

*Space Treatments (Aerosols, etc.):* The *advantages* include: currently common and effective practice in the industry; and several registered chemicals are already in use (dichlorovos, pyrethroids). The *disadvantages* include: penetration into machinery not as good as by fumigants.

### **Potential Alternatives (Short Term)**

*Controlled Atmosphere:* The advantages and disadvantages are discussed above. It is expected that continued research will yield improvement in efficacy and application beyond those currently available.

*Monitoring:* The advantages and disadvantages are discussed above. It is expected that continued research will yield improvement in efficacy and application beyond those currently available.

*Space Treatment:* The immediate benefits are limited, but it is expected that continued research will yield improvement in efficacy and application beyond the current level.

### **Potential Alternatives (Long term)**

*Expert Systems:* These have been described above and have similar application in milling and processing facilities.

### **Research Needs**

#### *High Priority, Short Term*

*Controlled Atmospheres:* Research is needed to: determine structural sealing requirements; determine relative efficacy and usefulness of carbon dioxide and nitrogen; investigate combining carbon dioxide or nitrogen with high temperatures and possibly phosphine to shorten the time requirement and make this alternative more suitable for a 48-hour time frame; and conduct full-scale studies of feasibility and optimize operational procedures.

*Monitoring:* Pest monitoring systems provide the foundation for all other control strategies. Research is needed to: develop methods to pinpoint sources of insects so that sanitation or spot treatments can be used instead of general fumigations; determine the efficiency of Coleoptera pheromone traps when used near cereal products; develop methods to relate trap catches to actual population densities and point sources of infestations; develop new or improve existing traps for major species of

storage pests; and develop automated trapping systems.

#### *High Priority, Long Term*

**Controlled Atmospheres:** Controlled atmosphere is a highly desirable treatment alternative. Because extensive data are available, short-term research (see above) should enable use in some facilities. However, longer term research should yield additional benefits. Combining controlled atmosphere with heat and other treatments may yield benefits as determined by long-term research.

**Monitoring:** Many improvements can be made in monitoring systems with short-term research investments (see above). However, monitoring systems can be further improved with longer term research efforts. Automated monitoring systems and pheromone traps for certain species may require long-term research.

**Expert Systems:** Decision support systems, along with monitoring, provide the foundation for integrated pest management systems and will be essential to the success of most of the alternatives being considered. A long-term research investment is needed to develop such systems for warehouse and processing facilities.

#### *Medium Priority, Short Term*

**Heat:** Much research and practical experience are available on heat treatment. Research is needed to: fill in gaps in time and temperature requirements to kill various insect species; investigate structural limitations and heat sensitivity of equipment; investigate penetration of heat into structural components and equipment; and fine-tune operational procedures to optimize times and temperatures in various kinds of facilities.

**Space Treatments (aerosols, etc.):** Such treatments are currently in use. Research is needed to: develop and register additional (and better) chemicals; and develop improved formulations and application techniques.

**Sanitation:** The value of sanitation is well established in the industry. Research is needed to: develop methods to identify sources of problems (whether from the raw commodity, within the facility, or the surrounding environment) so that control measures can be focused only where needed; develop methods to measure the effectiveness and need for sanitation; and improve the design of equipment and facilities, so that sanitation can be used effectively.

#### *Medium Priority, Long Term*

**Space Treatments (aerosols, etc.):** Short-term research will improve this technology (see above), but continuing, long-term research will be needed to develop additional chemicals.

#### *Low Priority, Short Term*

**Phosphine:** Phosphine is generally considered to be unsuitable for use as a structural fumigant because of its corrosiveness to copper wiring. However, research should be done to either confirm this or determine the kinds of situations where it would be applicable. In addition, some research is needed to determine the effectiveness of phosphine at elevated temperatures and with carbon dioxide.

**Crack and Crevice Treatments:** Research is needed to develop new and better chemicals.

#### *Low Priority, Long Term - None*

### **GRAIN SHIPMENTS, PACKING MATERIALS (QUARANTINE)**

This section deals with quarantine treatment of commodities. Major target pest is khapra beetle. Methyl bromide is used for occasional treatment of grain shipments, and routine treatment of burlap packaging from India, Sudan, Iraq, Iran, Pakistan, and other countries as a condition of entry. The approximate annual consumption of fumigant is 31,000 pounds. The scope of the pests is national and international.

Alternatives to methyl bromide should possess the following characteristics: 100% effective; good distribution and product penetration; no damage to product or vessel; and effective preferably within 24 hours but certainly not more than 48 hours.

### **Existing Alternatives and Their Attributes**

*Heat:* The *advantages* include: some data available on insect sensitivity; currently used in milling industry and for some quarantine applications; and may meet time requirement. The *disadvantages* include: potentially damaging to product, especially when steam is used; and operational problems with steam heat.

### **Other Feasible Alternatives and Their Attributes**

*Sanitation at Origin:* The *advantages* include: reduction in need for fumigation. As facilities are certified as to sanitation, the need to impose a mandatory treatment would be lifted. The *disadvantages* include: requirement of intensive monitoring; and inability to eliminate the problem.

### **Potential Alternatives (Short Term)**

*Controlled Atmosphere (nitrogen, carbon dioxide, "burner gas"):* Based on available data, nitrogen or carbon dioxide at 98% at 43° C has been effective in 6 hours. 85% to 95% carbon dioxide at 260 to 275 psi has been effective in 2-3 hours. Research has not been done on nitrogen at high pressures. The *advantages* include: existing technology already extensively developed; no damage to products; and reduction of required treatment time may be possible by combining with heat or pressure. The *disadvantages* include: need for combining with heat or pressure to reduce application time to acceptable interval; and requirement for a chamber for pressure use.

*Irradiation:* The *advantages* include: technology currently available; and already proven to be effective in disinfestation of grain and food. The *disadvantages* include: not applicable to brassware packaging; and equipment not readily available.

*Hydrogen Cyanide and Chloropicrin:* The *advantages* include: historical use in fumigation; and very fast acting. The *disadvantages* include: not currently registered; need for updated data; concerns for worker's safety; concerns regarding sorption and desorption; concerns regarding venting hydrogen cyanide to atmosphere; and corrosive.

*Heat:* It is expected that research could improve the usefulness of heat beyond its current level of applicability.

*Phosphine:* The *advantages* include current registration for commodity fumigation. The *disadvantages* include: corrosive; poor efficacy on khapra beetle eggs; and slow kill.

*Low Temperature (Cold):* The *advantages* include: documented use for fruit flies; and little or no product damage. The *disadvantages* include: higher energy requirement than heat; greater time requirement than heat; and unanswered questions regarding penetration.

### **Potential Alternatives (Long-term)**

New Fumigants: The development of new, acceptable fumigant materials is unlikely .

### **Research Needs and Priorities for Grain Shipments, Packing Materials (Quarantine)**

*High Priority, Short Term* - None

*High Priority, Long Term*

Controlled Atmospheres: Controlled atmospheres are generally too slow for quarantine applications, but preliminary research suggests that times can be shortened by combining carbon dioxide or nitrogen with either high temperatures or high pressures. Research is needed to determine optimum combinations. More research is needed on nitrogen than on carbon dioxide.

*Medium Priority, Short Term*

Heat: Research is needed to determine time requirements, penetration into products, potential for damage to products, and to develop operational procedures.

*Medium Priority, Long Term*

Irradiation: Research is needed to develop operational procedures and techniques for confirming the sterility of surviving insects.

Low Temperatures: Research is needed on product penetration, optimization of time and temperature requirements, and development of operational strategies.

*Low Priority, Short Term*

Sanitation at Origin: Research is needed to develop suitable techniques for monitoring effectiveness.

*Low Priority, Long Term*

Hydrogen Cyanide and Chloropicrin: These are not promising alternatives. However, their use would require extensive research to update dose and time requirements and develop means for aeration and atmospheric venting.

Phosphine: Experience indicates that phosphine has poor potential for quarantine use against khapra beetle.

New Fumigants: The development of new fumigants is unlikely and would require an extensive research commitment (see above).

## Session IV: Non-Food Products

Discussion Group: *Chairs*, Jennifer Sharp & Norm Leppla; *Members*, Guy Hallman, Arnold Hara, James Hansen, Mike Mullen, David Reeves, Jim Stewart

### INTRODUCTION

In 1991, APHIS supervised fumigations that used about 385,525 pounds of methyl bromide, (198,484 pounds for food and 187,041 pounds for non-food products). Only 4,000 pounds were used for plants but this accounted for 31% of the fumigations. Conversely, logs required 107,000 pounds for 11%. The other major use categories were packing materials for khapra beetle (27,000 pounds, 23%), tobacco (8,000 pounds, 10%), and a wide variety of miscellaneous plant materials. Nearly 80% was used for logs, khapra beetle and tobacco, with a similar amount for fumigating conveyances and structures. Considering both government and the private sector, about 8 million pounds of methyl bromide are used per year in North America for fumigating non-food products, and conveyances and buildings. This represents 6% of the total usage world-wide.

### CLASSIFICATION OF NON-FOOD COMMODITIES:

Non-food products are listed in the APHIS Plant Protection and Quarantine Treatment Manual, as Commodities Intended for Propagation (plants bulbs, tubers, and seeds), Miscellaneous Plant Materials (tobacco, cotton, cut flowers, khapra beetle infested materials, and logs), and Miscellaneous Products (railway cars, ships, bagging materials, and infested equipment). The existing 27 entries classified within these treatment categories were reorganized on the basis of methyl bromide usage and shared potential alternatives. Plants were placed in a single category and divided into cut flowers and trees, potted plants and succulents, propagative plants, bulbs and seeds, and

aquatic plants. Plant products with similar or minor usage were combined into logs, tobacco, cotton, packaging material (straw, vermiculite, excelsior, bags, jute, hog bristles, paper), dunnage (pallets, slip sheets, crates), and organic products (carpet, rugs, toys, baskets, hats). Structures were added to conveyances to include methyl bromide usage for both transport and storage.

The following write-up on alternatives to methyl bromide is divided into the following 12 sections: (1) Cut Flowers, Foliage and Christmas trees, (2) Potted Plants, (3) Vegetative Propagules, (4) Bulbs and Seeds, (5) Aquatics, (6) Logs, (7) Cotton, (8) Tobacco, (9) Packing, (10) Dunnage, (11) Conveyances and Structures, and (12) Organic Materials.

### COMMODITIES, PEST PROBLEMS, AND SCOPE

#### CUT FLOWERS, FOLIAGE, AND CHRISTMAS TREES

These are infested by a wide range of pests including surface feeders: homopterans, mites, caterpillars, beetles, and thrips, and internal feeders: leafminers, nematodes, gall formers, and borers. The scope of these pest problems is regional and national.

#### Existing Alternatives and Their Attributes

*Pest-free zones:* This concept involves shipping commodities from areas which are free of the pest or eradicating the pest in an area. It also means not using packing and dunnage that are infested with quarantined pests. The pest-free concept eliminates the need for a treatment. However, certifying an area pest-free may require constant trapping and monitoring.

*Chemical Dips and Sprays:* These are insecticides applied in a water immersion or used as sprays.

Borate treatment of logs is a promising chemical treatment. They are effective, well known, accepted, broad spectrum, and easy to use. Disadvantages are residues. Achieving registration would be costly and time consuming.

*Mechanical treatments:* These include compression of cotton bales, debarking of logs, and physically removing pests from the commodity. This treatment is useful for pests which can be easily and completely separated from the commodity.

### **Potential Alternatives (Priority)**

*Conductive Heat:* This includes hot water immersion, vapor heat, dry heat, and forced hot air. Heat treatments are well studied with some commodities, and their application is broad over a number of pests and commodities. They are of relatively short duration. In some cases the treatment may occur in transit. Heat often slows rot. Heat leaves no toxic residues. Heat may damage some commodities, especially living ones. It may cause flavor changes to tobacco. Heat requires a fair amount of energy; however, it costs less than other alternatives.

*Irradiation:* This includes gamma and X-ray. Initial construction may be expensive, and there is a potential safety hazard with radioactive sources. Irradiation treatment is rapid. There is a problem with consumer acceptance of irradiation; however, it leaves no radioactive residues, and extensive studies have found no health problem with irradiated commodities. However, infrequent disposal of spent radioactive source creates an environmental problem. A technical problem with irradiation is that usually not all of the insects are killed although the survivors do not reproduce. A marker is needed to determine if an insect found alive after treatment has been irradiated sufficiently to not reproduce. Some live commodities may be damaged by irradiation.

*Controlled Atmosphere:* This involves use of nitrogen or raising carbon dioxide levels and/or lowering oxygen levels to make the atmosphere toxic to insects. The treatment does not leave toxic residues. It has been studied considerably with the aim of preserving the quality of fresh commodities.

The treatment is fairly long, and some live commodities are damaged. Controlled atmospheres synergize well with heat and sometimes with fumigants.

*Systems Approach:* This approach is a series of steps in the production, management, processing, packaging, and shipping of a commodity, with each step reducing the risk of that commodity being infested. This eliminates the need for a treatment directly to the commodity. However, the systems approach is complex and susceptible to error without appropriate monitoring.

*Chemicals* - see above.

### **Potential Alternatives (Secondary)**

*Microwave Heat:* Used here to represent any radio frequency heat. It leaves no toxic residues and is applicable to a broad range of pests. Microwave is quite variable in heating. Although considerable research has been done with microwave, treatments have not been used.

*Cold Storage:* This comprises holding a commodity for a few days to a few weeks at temperatures below or slightly above freezing. The treatment is well known and has broad application. Toxic residues are avoided, although live commodities may be damaged. Energy cost is high and time relatively long. Insect survival often depends upon the ratio of temperature reduction - the faster the rate, the more effective the treatment.

*Physical Barriers:* These include wrapping, coatings, and other barriers which kill pests inside the barrier and/or prevent reinfestation. They are of limited use.

*Systemic pesticides:* These chemicals are taken up by the plant and translocated to all parts where they kill both interior and surface pests. They are well known, easy to use, cheap, and effective on a broad range of pests. Applicability is limited to cut and potted plants, and there it is not considered a priority. Residues and incomplete kill are problems.

## POTTED PLANTS

These are infested by the same categories of pests which attack cut flowers. The scope of these pest problems is regional and national.

### Existing Alternatives

*Pest-free Zones and Chemicals* - see above.

### Potential Alternatives (Priority)

*Controlled Atmosphere, Systems, Chemicals (fogs and aerosols)* - see above.

### Potential Alternatives (Secondary)

*Quarantine:* It implies holding a commodity in a pest-tight facility and inspecting it until all danger of pests emerging from the commodity has passed. It is not considered to be very promising because of the time involved and the facilities needed. Also, inspection may not find all of the pests.

*Heat, Microwave, Cold, Mechanical, and Systemics* - see above.

## VEGETATIVE PROPAGULES

The pests are same as for cut flowers. The scope is regional and national.

### Existing Alternatives

*Chemical, Mechanical, and Heat* - see above.

### Potential Alternatives (Priority)

*Heat, Pest-free Zones, Systems, Chemicals, Mechanical* - see above.

### Potential Alternatives (Secondary)

*Microwave, Controlled Atmosphere, Physical Barrier* - see above.

## BULBS AND SEEDS

The pests include those of cut flowers in addition to chalcids, bulb mite, bulb fly, ticks, and snails. The scope of these pest problems is regional and national.

### Existing Alternatives (see above)

### Potential Alternatives (Priority)

*Heat, Cold, Controlled Atmosphere, Chemicals, Physical Barrier* - see above.

### Potential Alternatives (Secondary)

*Microwave, Pest-free Zones, Systems* - see above.

## AQUATICS

The pests include external and internal feeders and snails. The scope of these pest problems is regional and national.

### Existing Alternatives

*Chemicals* - see above.

### Potential Alternatives (Priority)

*Chemicals* - see above.

### Potential Alternatives (Secondary)

*Pest-free Zones, Quarantine*

## LOGS

The pests include bark- and wood- boring insects, nematodes, fungus, and bacteria. The scope of these pest problems is regional and national/export.

### Existing Alternatives

*Kiln drying, Debarking, Borate dip.*

## Potential Alternatives (Priority)

*Fumigants (other than methyl bromide):* Sulfuryl flouride and phosphine are potential fumigants. Residues may be a problem. Fumigants damage some commodities; phosphine even corrodes some metals containing copper, such as brass and bronze.

## Potential Alternatives (Secondary)

*Processing:* A treatment would not be necessary. An advantage is that jobs would be created for the exporter. However, often the market exists for the raw and not the processed product. In any case, this technique would only be applicable to a few commodities, such as logs and cotton.

*Controlled Atmosphere, Pest-free Zones, Systems* (see above).

## COTTON

The pests include diapausing pink bollworm larvae in seed. The scope of this pest problem is international.

## Existing Alternatives

None for cotton lint; hydrogen cyanide, phosphine, or heat for seed (cotton seed for edible oil and meal not covered in this section).

## Potential Alternatives (Priority)

*“No treatment”:* It infers that there is no biological basis for the quarantine, that the pest already occurs in the country imposing the quarantine. The advantage is that no treatment would be necessary. We feel this is a priority for tobacco and cotton.

## Potential Alternatives (Secondary)

*Irradiation, Cold Storage, Mechanical, Processing.*

## TOBACCO

The pests include cigarette beetle, and tobacco moth. The scope of these pest problems is regional.

## Existing Alternatives

*Phosphine, Steam, Insect Growth Regulators (Kabat®), Controlled Atmosphere.*

## Potential Alternatives (Priority)

*Microwave, Irradiation, No treatment.*

## Potential Alternatives (Secondary)

*Cold Storage, Pest-free Zones, Systems.*

## PACKING MATERIALS

The pests include: khapra beetle, ants, ticks, nematodes, wood borers, and hitch-hikers. The scope of these pest problems is regional, national and imports/exports.

## Existing Alternatives - None.

## Potential Alternatives (Priority)

*Heat, Pest-free Zones, Fumigants, and Chemicals.*

## Potential Alternatives (Secondary)

*Microwave, Irradiation, Systems, Mechanical Barrier, and No treatment.*

## Dunnage

The pests include wood borers, wasps, snails, and nematodes. The scope of these pest problems is regional/national.

## Existing Alternatives - None.

## Potential Alternatives (Priority)

*Heat, Pest-free Zones, Chemicals, and Fumigants.*

## Potential Alternatives (Secondary)

*Microwave, Irradiation, Systems, Mechanical, Physical Barrier, No treatment.*

## CONVEYANCES, AND STRUCTURES

The pests include termites, borers, stored product pests, khapra beetle, cockroaches, and rodents. The scope of these pest problems is regional, national, and international.

### Existing Alternatives

*Heat and Quarantine.*

### Potential Alternatives (Priority)

*Fumigants and Chemicals.*

### Potential Alternatives (Secondary)

*Cold Storage, Controlled Atmosphere, Mechanical, Physical Barrier.*

## ORGANIC MATERIALS

The pests include khapra beetle, stored product pests, termites, wood borers, fabric pests, cockroaches, and rodents. The scope of these pest problems is regional and national.

### Existing Alternatives

*Irradiation and Cold Storage.*

### Potential Alternatives (Priority)

*Heat, Microwave, Fumigants, Chemicals.*

### Potential Alternatives (Secondary)

*Controlled atmosphere.*

## RESEARCH NEEDS AND PRIORITIES

*High Priorities, Short Term*

Improve methods of using fumigants and chemicals in most cases.

Application of conductive heat for cut plants, propagules, seeds, bulbs, tobacco, conveyances, structures, and organic materials.

Pest-free concepts for cotton, packaging, and dunnage. This means replacing packaging and dunnage with non-host materials and exporting cotton from pink bollworm-free areas.

Removing and cleaning of pests from cut plants and propagules and debarking of logs.

Cotton and tobacco may not need quarantine treatments depending on decisions as to whether their pests are of quarantine significance; i.e., do they already exist in importing countries.

*High Priority, Long Term*

Systems and pest-free approaches for cut plants, propagules, and potted plants.

*Medium Priority, Short Term*

Microwave heating for seeds, bulbs, and tobacco.

Irradiation for tobacco and organic materials.

Coatings and waxes for seeds.

*Medium Priority, Long Term*

Controlled atmosphere for potted plants and seeds.

*Low Priority, Long Term*

Systems approach for seeds, bulbs, logs, cotton, tobacco, packaging material, dunnage, conveyances, and structures.

Microwave heat for cut plants, potted plants, propagules, packaging, and dunnage.

Irradiation for potted plants, logs, cotton, packaging, and dunnage.

Controlled atmosphere for propagules, logs, cotton, conveyances, structures, and organic materials.

Physical barriers such as wrapping and coatings for cut flowers, propagules, packaging, dunnage, conveyances, and structures.

Pest-free concept for seeds, bulbs, aquatic plants, logs, and tobacco.

## **ALTERNATIVES FOR QUARANTINE TREATMENTS**

The 27 non-food categories listed in the USDA APHIS Plant Protection and Quarantine (PPQ) Treatment Manual (1992), were categorized into three broad groupings: (1) Plants, (2) Miscellaneous Plant Materials, and (3) Conveyances/Structures.

Plants represent 31% of the treated commodities and 4,000 pounds of methyl bromide use; miscellaneous plant materials represent 11% of the treatments and 107,000 pounds of methyl bromide use; and khapra beetle infested materials and related pests in ships, boxes, railway cars, trucks, and airplanes (conveyances/structures) represent 23% of the treatments and 27,000 pounds of methyl bromide use. About 10% of methyl bromide is used to disinfest agricultural non-food products. Five percent of the total methyl bromide use is for plants and plant materials and 5% is for conveyances/structures. This represents a small but very important use for methyl bromide. Alternate treatments are needed to allow continued trade. Treatments must be broad spectrum because cargo containers often have variable cargo including mixed commodities as dunnage, packing materials, tobacco, cotton bales, and plants. One broad spectrum approach is use of systems. Systems approaches have been an overlooked quarantine area needing major attention. The use of integrated pest management systems requires new paradigms. Effective treatments as systems may require several days or weeks to provide quarantine security. The alternate approaches will require that effectiveness be based on quarantine security and not necessarily rapidity of kill.

Effective quarantine treatments for non-food products were classified into existing, feasible, and researchable alternates.

## **PLANTS**

**Existing Alternatives:** heat, pest-free, chemical, mechanical, physical barrier.

**Feasible Alternatives:** microwave, cold, quarantine, systemics.

**Researchable Alternatives:** irradiation, controlled atmosphere, systems, fumigants.

## **MISCELLANEOUS PLANT MATERIALS**

**Existing Alternatives:** heat, fumigants, chemical, mechanical.

**Feasible Alternatives:** cold, physical barrier, quarantine, processing, no treatment.

**Researchable Alternatives:** microwave, irradiation, controlled atmosphere, pest-free, systems.

## **CONVEYANCES/STRUCTURES**

**Existing Alternatives:** heat.

**Feasible Alternatives:** cold, controlled atmosphere, systems, mechanical, physical barrier, quarantine.

**Researchable Alternatives:** controlled atmosphere, heat, cold, pest-free.

**RESEARCH NEEDS:** Research must continue to identify alternate treatments for methyl bromide fumigation and procedural methods must be examined. By using plastic dunnage in place of wood, wood-infesting pests could be reduced or eliminated. Replacing straw and hog bristles as packing materials with synthetic materials reduce the risk of hitch-hiking pests. Ideas and approaches have been summarized which will be useful in the development of new paradigms.

# *SOIL FUMIGATION*

## Session V: Strawberry

Discussion Group: *Chairs*-John Duniway, Jim Locke; *Participants*-Bob Baldwin, Don Dickson, Ray Frank, Deborah Fravel, Gene Galletta, Ronald Korcak, Lorin Krusberg, John Maas, James Marois, Albert Paulus, John Potter, Becky Westerdahl

### INTRODUCTION

Methyl bromide is critical in most commercial shipping strawberry production systems. It is a major soilborne pest management option that has resulted in intensive, predictable, and profitable production systems for 30 years. While alternative soilborne pest management materials and approaches are possible, none has the full spectrum of activity and reliability of methyl bromide. This is probably the case in both the near and long term. All alternative soilborne pest management materials and approaches will need research and development before implementing in current strawberry production systems. Also, methyl bromide has important synergistic, enhancing effects when used with chloropicrin for controlling soilborne pathogens, many weeds, and killing volunteer strawberry plants for annual plantings (very important in California and Florida), as well as giving a growth and yield response.

In nursery phases of strawberry production, pathogen-, nematode-, insect-, and weed-free propagation is of primary importance. In fact, some certification programs currently require use of methyl bromide. There are no alternative chemical fumigants for quarantine, and the alternatives for nursery production do not yet approach the level of control needed. Alternative measures (e.g. steam) that do afford adequate levels of control are prohibitively expensive. High land cost, limited land availability, and possibly other considerations limit options for many alternative approaches, such as (but not limited to) crop rotation and fallowing. While major soilborne pests are controlled by methyl bromide, withdrawal of methyl bromide

will likely lead to new problems that are not now evident, such as insects and pathogens resident in crop debris. In fact, not all soilborne insect and plant pathogen risks or threats are known at this time.

### Pathogens

*Verticillium Wilt*: A national problem with up to 100% losses in some areas, especially when the pathogen can build up in the soil over time. *Verticillium wilt* is the number one strawberry disease problem during production in California.

*Phytophthora*: A variety of root, crown, and fruit rots caused by the *Phytophthora* species are a national problem with up to 100% loss depending upon environmental conditions and irrigation. Methyl bromide is not fully effective, but is beneficial.

*Anthracnose*: A national problem with up to 100% yield loss if environmental conditions are conducive to infection and disease development. A complex of three fungi is involved (*Collectotrichum fragariae*, *C. gloeosporioides*, and *C. acutatum*). It is an important fruit rot in California, and a general crown and foliage disease in the East and South United States. It is likely that methyl bromide use is more important in the nursery to assure pathogen-free stock than to control the fungi in production fields.

*Rhizoctonia Root/Crown/Terminal Bud Rot*: *Rhizoctonia* is a national problem, particularly in areas with heavy soils. Thus, it is a major problem in the Northeast.

*Diseases of Unknown Etiology*: Black root rot complex may be caused by *Pythium* species, but other organisms may also be involved. Control of this disease with methyl bromide + chloropicrin is at least partially responsible for the "yield re-

sponse” attributed to methyl bromide. This disease complex is a national problem, but more severe in high-yielding systems such as in California and Florida.

**Nematodes:** A national problem which involves several different species that can form complexes with some other pathogens. In the Northeast and Southeast, the lesion nematode is most important, while it is of minor importance in California when methyl bromide is used. The foliar nematode is a major problem in California, while it is of minor importance in Florida. Root-knot nematode is a major problem in the East and in California, while it is of minor importance in Florida. The sting nematode is a major pest problem in Florida, while it is of minor importance in the East. The sting nematode is quarantined in California.

**Weeds:** Weed control has been one of the main reasons for methyl bromide use in many locations. Even though methyl bromide does not control all weeds, it controls a broad spectrum of annual and perennial species.

**Perennial Weeds:** Yellow and/or purple nutsedge are regional problems.

**Annual Weeds:** Annual broadleaf and grass weeds are widespread.

**Various Weeds:** Regional distribution and importance

## Insects

**Soilborne and Debris-borne Insects:** Soil- and debris-borne insects such as root weevils, white grubs, cyclamen mite and others, are a national problem; however, the overall importance is unknown. The problem, nevertheless, is likely to increase without methyl bromide which also kills existing plants before replanting in annual systems.

## EXISTING ALTERNATIVES

### Control of Wilt:

**Chloropicrin:** Chloropicrin is available and is effective. Most of the technology is in place, but the fumigant is a tear gas and drift problems may be increased. It is the active ingredient of methyl bromide-chloropicrin combination for *Verticillium* control.

**Vapam®:** Vapam® is available and is effective with technology in place. New application technology may improve the efficacy of Vapam®. An *advantage* is that it may have minimal impact on the environment. A significant *disadvantage* is that it may increase the time to planting after fumigation.

**Basimid®:** Basimid® has future potential, but it is currently not registered for use on food crops. Application for food uses is in progress, but it may require three years or longer. Application technology is critically short, but under development. In cooler soils, it may take up to 60 days before planting can occur after application.

**Genetic resistance:** Genetic resistance is present in some commercial lines in the Northeast, but not in California or Florida lines. The *advantage* of this approach is that if incorporated, it could last a long time (based on experience with other crops with *Verticillium* resistance). No negative impact on the environment, except possible selection for new pathotypes of the pathogen. Time to develop genetic resistance maybe 5 years to more than 20 years.

**Biological Control:** Biological control is a long-term prospect that may be enhanced with applications of sublethal doses of fumigants, or combined with other soilborne pest management strategies. However, biological control probably will not be as effective overall as methyl bromide for management of soilborne pests. Registration, formulation, and application may be problems because of possible negative perception of microbes. Research is underway on the biocontrol of *Verticillium* of other crops, but not on strawberries.

*Soil Solarization:* Soil solarization may be applicable in some situations, but this approach will be difficult to fit into cropping systems without losing at least one year of production in most cases. It may be a useful approach in combination with other approaches, such as biological control. Disposal of plastic (or other) tarping material is a problem if not used as mulch.

### **Control of *Phytophthora* Root, Crown, and Fruit Rots**

*Fungicides:* Fungicides are available and registered (Ridomil®; Aliette®) but control of *Phytophthora* species is not optimal. These may be applicable in the field for disease control during production, but not appropriate for nurseries where the pathogen must be eliminated. Pathogen resistance has developed with continuous use of fungicides. Fungicide degradation in the soil may be too fast for effective activity.

*Genetic Resistance:* Genetic resistance partially exists in some lines. The potential exists for more resistance against several species of *Phytophthora*. Improved methods for identifying and evaluating resistance to *Phytophthora* species are needed.

*Vapam® and Chloropicrin:* Vapam® and chloropicrin are available and registered. These may provide some control, but research is needed to determine how deep the fumigants may be effective. Because very low levels of the pathogen(s) can cause high yield losses, nearly complete kill is required for effective control.

*Cultural Practices:* Cultural practices for effective, but usually partial, management of soilborne plant pests involve primarily reducing standing water through alteration of irrigation methods, drainage, and field design. Raising the soil pH may also lessen pathogen damage.

### **Control of Anthracnose**

*Genetic Resistance:* Genetic resistance to specific pathogens exists in some lines. However, incorporation into commercial cultivars is long term. In

addition, the stability of such resistance in commercial cultivars is unknown. A regional perspective is important because there are different pathogens in different production areas. This approach will have low environmental impact, but disease control will probably be partial and will require application of supplemental fungicides.

Fungicides are registered, mostly captan used, but reentry time has reduced its value to growers or cause farmers to wear protective clothing. New materials are unlikely. Effectiveness is dependent upon weather. They can be applied to crop for fruit rot and general disease control.

*Vapam®, Chloropicrin, and Basimid®:* The effectiveness of these fumigants alone or in combination is unknown.

*Biological Control:* Unknown

### **Control of *Rhizoctonia* Root/Crown/Terminal Bud Rot**

*Chloropicrin and Vapam®:* Chloropicrin and Vapam® are available and control is good (see above).

*Rhizolex®:* Rhizolex® is a fungicide under development and currently has no registered uses in the United States. It is a preplant furrow application. Thus, it must be put on as a prophylactic.

*Genetic Resistance:* Genetic resistance is unknown, but implementation will be very long term if available at all.

*Biological Control:* Biological control potential has been identified in other crops, but development and implementation are long term. This approach may be more likely if combined with sublethal levels of soil fumigants.

### **Control of Diseases of Unknown Etiology**

*Annual Plantings:* Strawberry production systems could change to more annual plantings.

*Chloropicrin, Vapam®*, and *Basimid®*: These chemicals are not as effective as methyl bromide at this time. However, chloropicrin affords some yield increase. A positive yield response to chloropicrin may not be as significant without methyl bromide.

There is a need to determine the etiology(-ies) of this(these) disease(s) before future disease management strategies can be developed and implemented.

## **Control of Nematodes**

*Telone®*: Telone® is available as a soil fumigant and gives good control of nematodes. It is presently suspended in California, but reregistration is being pursued. The registration future of this compound is questionable.

*Chloropicrin and Vapam®*: Chloropicrin and Vapam® are available. However, these fumigants have marginal activity due to poor distribution in the soil.

*Enzone®*: This compound has some potential as a nematicide. However, its registration status is unknown.

*ClandoSan®*: This compound is available, but its efficacy is unknown. The registrant may withdraw its application.

*Basimid®*: Basimid® has potential, but is currently not registered for food crops.

*Genetic Resistance*: Genetic resistance has potential. There are known sources for resistance to foliar and root-knot nematodes; tolerance is known for the lesion nematode; and no resistance is known for the sting nematode. Long-term potential is promising.

*Soil Solarization*: The technology/methodology exists; however, this approach is dependent upon the environment and may be limited to only a few areas. Other disadvantages include shallow depth penetration of heat into the soil and a narrow window for treatment in strawberry cropping systems.

*Heat Treatment*: Heat treatment technology exists and may be applicable in nursery situations. This approach is very expensive and slow, and may require high levels of energy input.

*Cultural Practices*: Crop rotation has potential. Usually only one year of production is lost. However, clean fallow is best. Trap crops may have some potential against endoparasitic, but not ectoparasitic, nematodes. The overall effectiveness of these practices is unknown at this time.

*Crop Residue/Extracts/Green Manure*: Soil amendments, including Sesame chaff, marigold, sudan grass, rye, corn, glucan meal, and poultry litter have been evaluated with mixed results. Care must be taken because residue may stimulate nematodes or damage strawberries. Extensive research over the long term is needed.

*Biological Control*: Biological control potential has been identified for some species but development and implementation are long term.

*Pathogen-free Stock*: Methodology (hot water dip) exists and is effective. This approach is limited to certified nursery stock. Hot water treatment may be harmful to plants or promote fungal problems.

## **Control of Insects**

*Fumigants*: Chloropicrin and Vapam® are available. Basimid® is under development.

*Chemicals*: Chemical insecticides exist. However, it is difficult to reach target organisms. The potential for overall increase in pesticide use is a disadvantage.

*Genetic Resistance*: Genetic resistance or tolerance exists and can be developed further. However, this approach will not provide complete control. Varieties with specific soil- and debris-borne insect pest resistance/tolerance will be developed in and adapted to specific regions.

*Biological Control*: Biological control has potential, and is being used to control mites. This ap-

proach is less likely to be a viable strategy for controlling insects below the soil surface.

## Control of Weeds

*Pest-free Planting Material:* Weed-free planting material exists. However, soil treatment (methyl bromide fumigation) at the nursery is required.

*Fumigants/Chemicals:* Chloropicrin is available but has only minor activity against weeds. Vapam® is also available but is less effective against weeds than methyl bromide. Basimid® is under development but is also less effective against weeds than methyl bromide. Effective strawberry production will require additional herbicides in combination with these soil fumigants.

Herbicides exist, but may have limited utility without the use of other practices, such as crop rotation. Some are not appropriate in nurseries because of the inhibition of runner formation. Phytotoxicity to the crop is unknown in most cases, but must also be considered. The end result of the loss of methyl bromide will be an overall increase in pesticide use.

*Cultural Practices:* Crop rotations and cover crops are available in some locations. However, these options have limited applications in other areas. Alternative cover crops must be chosen to reduce weeds rather than increase them, as can happen with nematodes. These strategies for soilborne weed seed management may be limited by unavailability of land.

*Mulches,* such as clear and dark plastics, are available and used in some situations. However, weeds in planting holes are a problem. Many perennial weeds like nutsedge grow through the plastic mulch. Grasses and insects are a problem between mulched areas.

*Mechanical cultivation* is available or renovation, but is of limited application in mulch systems. Machinery and labor costs may be high.

*Biological Control:* Biological control may be possible for some weed species. For example, a rust disease pathogen is being evaluated to control nutsedge. Most biological control agents are weed species specific. In addition, they may not be adaptable to annual cropping systems.

*Physical Methods:* Steam or other heating of soils exists, but is too expensive for any application other than possibly nursery production. Soil solarization is under development. However, development of this approach for strawberry production is long term. Nutsedge and some other weeds are not controlled by soil solarization. The efficacy of soil solarization for weed management is dependent upon the climate and proper timing.

## ALTERNATIVE APPROACHES

### Chemicals - Fumigants

Further development of application technology and databases on the effectiveness of alternative chemical fumigants is a high priority in the near term. Development of alternative soil fumigants needs strong cooperative effort between the private and public sectors. In general, application equipment and expertise are available, but there is a need to improve application technology to optimize specific materials for strawberry production.

### Chloropicrin:

**Priority:** High for the near term. Most likely methyl bromide replacement in California, at least in the short term.

**Attributes and Potential for Success:** Growth and yield responses similar to methyl bromide. Currently registered, but does not give full spectrum and level of pest control possible compared to methyl bromide. This is especially true for weeds. It also requires careful soil preparation.

**Needs:** Need to optimize control with modern application equipment and plastic mulch. Must demonstrate effectiveness in some areas. Because

it is a well established chemical, there is an important role for the private sector to play in further research and development.

**Advantages and Problems:** Inadequate weed control, less effective than methyl bromide for nematode control. Drift can be noxious (tear gas). Requires 2-week aeration period before planting. May be subject to increased regulation in long term.

### **Vapam® (Metham-sodium):**

**Research Priority:** High for near term. Improvements needed in application technology, especially with irrigation under plastic mulch by drip, spray on soil surface and soil rollover.

**Attributes and Potential for Success:** Activity against most soil pathogens is high, about 70% as good as methyl bromide against nematodes and often has less consistent results than methyl bromide. Vapam® does not give the growth response that methyl bromide and chloropicrin do.

**Needs:** Application technology research will improve efficacy. Especially needed is technology to improve depth of control of pathogens and nematodes. Efficacy data are needed in some areas. The potential to use sublethal dosages with biological control agents exists.

**Advantages and Problems:** Narrow spectrum of activity against weeds. Less consistent pathogen control than methyl bromide. Objectionable odor. Increase regulation issues are possible in the long term. Two-week waiting period to plant. Less mobile in soil than methyl bromide. Residual actinomycetes and bacteria are left in soil. These may buffer soil against the rapid reinvasion of pathogens.

### **Telone®:**

**Research Priority:** Medium. Registration status needs clarification to warrant further research. Presently not allowed in California.

**Attributes and Potential for Success:** Good nematode control. No control of weeds or fungi unless used with chloropicrin (Telone C-17® is a product with 17% chloropicrin). Insect control is uncertain.

**Needs:** If registration prospects are good, there is a need to try other combinations with chloropicrin to increase efficacy to control weeds and fungi.

**Advantages and Problems:** Not registered in California, but registration is being pursued. EPA currently has registration under review. This compound has been reported to be carcinogenic.

### **Chemical - Nonfumigants:**

**Priority:** High in short term, especially for weed control. Medium in long term.

**Attributes and Potential for Success:** Short-term supplement (except for *Verticillium* wilt). Basic efficacy data are available for fungicides; however, additional data are needed within 5 years. New products for *Phytophthora* species and weeds are currently under development, but residue studies require 10 years to complete.

**Needs:** Application technology must be developed for Basimid®. Evaluation of Enzone® (produces carbon disulfide) as broad-spectrum biocide is needed.

**Advantages and Problems:** Enzone® produces (carbon disulfide). Use of Basimid® requires a 60-day waiting period for re-entry in cool soil. Effective crop production systems, depending on which chemicals are used, will likely result in an overall increase in the total amount of chemicals used compared to methyl bromide-based crop production systems. This will be due to the need to use multiple products with narrower activity spectrums. In addition, the potential for ground water contamination, worker exposure, and residues in food is expected to increase. The liability issues for registrants are high because strawberry is a very high value crop, but grown on limited acreage (small market, but high value equals high risk with

small return). Geographic regional studies are required on fairly large acreage. Most fungal plant pathogen control by chemicals is fungistatic rather than fungicidal. Therefore, use of fungistatic chemicals is not appropriate for nurseries and pest-free planting stock material programs.

### **Genetic Resistance**

Priority: High for both short and long term. Approximately 5-10 years minimum required. However, greater benefits are potentially possible in the long term.

Attributes and Potential for Success: Germplasm exists with useful levels of resistance/tolerance to several important pests and diseases. This material needs to be screened, evaluated and selected against more complex pathogen/pest complexes in soil, i.e., move programs off methyl bromide treated systems. Prospects for combined resistance/tolerance to multiple pests and diseases exist. Regional cooperation will be needed to incorporate broader resistance into locally adapted varieties. Both public and private breeders exist.

Advantages and Problems: Need sources of resistance to *Rhizoctonia*, *Pythium*, and black root rot. Need to clarify the etiology of some root problems and growth suppression. Considerable time and effort are required to optimize. Very great advantages when can be done.

Needs: Need good cooperative teams of breeders, pathologists, nematologists, and entomologists to develop progressive, multipest screening/evaluating technology. Need germplasm evaluation. Need good methods to evaluate partial resistance. Prospects for better nematode tolerance and better *Verticillium* control are good. Need good cooperation between private and public sector breeders.

### **Sanitation (Pathogen-free Plant Material)**

Research Priority: High in both short and long term

Attributes and Potential for Success: Environmentally sound (low environmental impact). Currently mandated by certification in some cases. Tolerances may change with loss of methyl bromide.

Advantages and Problems: Limited to nursery stock production. Currently achieved to some extent with methyl bromide. Hot water treatment may predispose planting stock material to fungal pathogens.

Needs: Certification requires near zero tolerance. Without methyl bromide there is an increased potential for dissemination of nematodes, fungi, and weeds.

### **Cultural Practices (crop rotations, fallowing, crop residues, organic amendments, crop nutrition management, site selection, bed structure)**

Research Priority: High in short term; medium in long term

Attributes and Potential for Success: Environmentally sound (low impact). Many approaches already in use (site selection, bed structure, rotation with broccoli or other brassicas in Salinas Valley). Crop rotations and crop residues may have multiple benefits, including increased options for biological control. Most likely potential for application is in perennial culture. Sandy soils support less *Rhizoctonia* and *Phytophthora*.

Advantages and Problems: Crop rotations and fallowing are not economically feasible in many areas. Pressure to use marginal land likely to increase. Some crop residues are phytotoxic to strawberry and organic composts may reduce yields. Some crop rotations and cover crops are known to support or increase soilborne pest populations.

Needs: Additional basic research on crop residues is needed. Ideally, crops with case value (brassicas) are needed. There is a need to reoptimize crop nutrition levels in the absence of methyl bromide, and to determine the interaction with some pathogens (e.g., *Verticillium*).

## Biological Control

Research Priority: High in long term

Attributes and Potential for Success: Environmentally sound (low impact and risk). Highly pest target specific. This may be an advantage for registration because potential biological agents are safe with respect to impact on non-target species. However, disadvantages include limited market and need to combine with other treatments for other pests not affected (especially weeds). Biological control agents can be combined with chemical treatments to increase efficacy for fungi and nematodes. Considerable knowledge base is available in public sector for potential pathogen and weed control agents. Commercial partners are needed for further development. There is opportunity for genetic manipulation to increase usefulness. This is long term, high risk, and is dependent upon the public sector for early screening and development.

A systems approach to consider microbial community interactions may give some broad-spectrum disease suppression of the kind claimed for some organic systems. Control will be partial and long term trials will be needed for development.

Advantages and Problems: Research is high risk and is hindered at all levels including original search, small scale testing, product development, and regulatory approval.

Needs: Coordination of screening/evaluation efforts. Better formulation and delivery technology. Integration with other treatments ( fumigation, soil solarization).

## Soil Solarization (Physical Heating of Soil)

Research Priority: Medium to long term (10-20 years). Moderate chance of success. Better if combined with other treatments such as chloropicrin or biological control.

Attributes and Potential for Success: Only effective in certain climates and windows of time. Window of opportunity is limited in many locations. May require more time than possible in many cropping systems. Only partial control obtained. Will require integration with other measures. When integrated with other treatments, may be as good as methyl bromide in some situations. May enhance microbial suppressiveness of soil to diseases.

Advantages and Problems: Gives less positive growth response than methyl bromide. Plastic disposal problem if not used as mulch for crop.

Needs: Ideal conditions needed for maximum effectiveness. Must determine if weather, soil, and cropping systems will allow use. Research combination with chloropicrin and other biological approaches or Vapam®. Need to integrate, when possible, use of same plastic for crop.

## Steam

Research Priority: Only realistic for certain nursery applications.

Attributes and Potential for Success: Can be very effective. Considerable research has been conducted on the influence of temperature, duration and impact on/effect(s) of different soil types. Also, research and experience using sublethal temperature (pasteurization) to leave the beneficial organisms as a buffer while destroying the more heat sensitive plant pathogens.

Needs: Optimization for large-scale nursery applications (about 10,000 acres) nationally.

Advantages and Problems: Expensive. High energy input.

## Electronic Heating

Research Priority: Medium in long term.

Attributes and Potential for Success: New methods of electronic energy transfer (microwave, pulse, conduction) to heat soil and/or specifically kill pathogens. Needs to be tried. May have nursery and wider application.

Needs: Need prototype engineering to determine feasibility.

**RESEARCH NEEDS (see priorities under Alternative Approaches above),**

*High Priority, Short Term*

Develop database on likely alternatives to methyl bromide in order to develop predictable systems for soilborne plant pest management.

Develop existing alternative chemical fumigants and application technology.

Develop and evaluate alternative non-fumigant chemicals for weed control.

Develop and evaluate genetically resistant/tolerant germplasm.

Develop pathogen-free planting material programs.

Develop effective soilborne plant pest management based cultural practices.

*High Priority, Long Term*

Develop and evaluate genetically resistant/tolerant germplasm.

Develop pathogen-free planting material programs.

Develop biological control agents and integrate these into effective soilborne plant pest management systems.

Develop effective integrated soilborne plant pest management systems.

*Medium Priority, Long Term*

Develop cultural practices for incorporation into soilborne plant pest management systems.

Develop effective soil pasteurization technology, including (but not limited to) soil solarization, electronic heating, and steam.

## Session VI: Tree Fruits and Nuts, Small Fruits, and Miscellaneous Fruits

Discussion Group: *Chairs*-John Mircetich, Pete Timmer, Wayne Wilcox; *Participants*-Greg Browne, James DeVay, Clyde Elmore, Jeffrey Granett, Mike McKenry, Andrew Nyczepir

### INTRODUCTION

The commodities addressed in this section include a wide range of tree fruits, tree nuts, small fruits, and miscellaneous fruits. Methyl bromide fumigation is widely used for most field nurseries for all of these crops. Field orchard and vineyard sites are fumigated prior to setting out grapes, many fruit and nuts, and citrus in many locations in California. Preplant fumigation is used locally in other areas of the country to combat replant problems, soilborne fungal pathogens, and nematodes affecting a wide variety of fruit crops.

These crops are deep-rooted, perennial plants with productive life spans of 20-50 years. Therefore, pest management strategies must eliminate or suppress soilborne pathogens and insects over long periods of time. Furthermore, the deep-rooted nature of these plants presents unique problems relative to the extensive soil volumes that must be treated or affected. Thus, techniques or methodologies developed for shallow-rooted annual crops will not necessarily be applicable to tree and vine crops. Finally, the specific alternative technologies and strategies discussed below will provide only partial pest management relative to methyl bromide. Therefore, their successful use will require the development, testing, and implementation of integrated, multi-component pest management programs and strategies in order to be economically acceptable. Methyl bromide alternatives must be appropriate and applicable to deep-rooted perennial crops with 20-50 year production cycles, and must provide long-lasting pest control or be capable of reapplication.

### COMMODITIES, PEST PROBLEMS, AND SCOPE

The commodities include stone fruits (peach, nectarine, prune, plum, apricot, almond, sweet cherry, sour cherry), pome fruits (apple, pear), citrus (orange, lemon, tangerine, grapefruit, tangelo, temples), grapes, blueberry, brambles (raspberry, blackberry, loganberry), and miscellaneous fruit crops (kiwifruit, olive, avocado).

These commodities are affected by a wide range of soilborne pathogens and insect pests during production. All of these commodities are affected by nematodes, *Phytophthora* species, and *Armillaria* species (*Clitocybe* species).

Miscellaneous root and crown fungal pathogens (occasionally severe, but of local importance, e.g., *Rosellinia* species, *Phymatotrichum* species, *Xylaria* species, and *Sclerotium* species) also affect all of these commodities. Stone fruits, brambles, tree nuts, and miscellaneous fruit crops are affected by *Verticillium* species. Nematode-transmitted viruses affect stone fruits, pome fruits, grapes, brambles, and tree nuts. Numerous insect pests, including grape phylloxera, woolly apple aphid, citrus root weevil complex, and ten-line June beetle, affect all of these commodities. All weed species are important in nursery situations. Nut-sedge is of primary importance in production fields.

The scope of these insect and pathogen problems on these commodities is generally national. Depending upon the commodity, some of these pests are regional problems.

## EXISTING ALTERNATIVES

### Commercial Fumigants

*Telone II® (1,3, dichloropropene)*: Telone II® is an effective nematicide in many situations. However, this soil fumigant is not effective against weeds and fungi or in orchard replant situations where significant root residues are present. Telone II® is currently not available for use as a soil fumigant in California. Effective dosages required for acceptable pest management are higher than those likely to be approved for future use in California. Telone II® is highly volatile and off-site movement/drift may be a problem in some situations.

*Telone C-17®*: Telone C-17® has the same advantages as Telone II® but also provides control of some soilborne fungal pathogens. The disadvantages of C-17® are the same as those for Telone II® (and of chloropicrin) and drift can be noxious (tear gas).

*Vapam® (Metham-sodium)*: Vapam® is a relatively wide spectrum soil fumigant with activity against several different categories of pests, including certain soilborne fungal pathogens, nematodes, insects, and weed seeds. However, some important soilborne plant pests (nutsedge and some plant parasitic nematodes) are not controlled by Vapam®. Labeled rates for Vapam® use are insufficient to control root-inhabiting pathogens (*Phytophthora* species, *Armillaria* species, some nematodes). A long waiting period between application and planting is required. Effective application of Vapam® requires use of a sprinkler or drip irrigation system. There is potential for surface or ground water contamination, and off-site movement/drift of vapors.

*Chloropicrin*: Chloropicrin is effective against some soilborne fungal pathogens and insects but is not effective against weeds. A long waiting period is required between application and planting. The effectiveness of chloropicrin against important plant parasitic nematodes is uncertain or unknown.

There is potential for off-site movement/drift of vapors.

*Basimid® (Dazomet)*: The attributes of Basimid® are generally the same as those of Vapam®. Basimid® breaks down in the soil to the same active ingredient as Vapam®. The granular formulation of Basimid® reduces off-site movement/drift, but specific application procedures need to be developed for many tree and vine crops. Inadequate waiting period between application and planting or insufficient water at time of application may result in phytotoxicity.

### Chemical Pesticides

*Fungicides/Nematicides/Herbicides*: Chemical fungicides, nematicides, and herbicides available for soilborne plant pest management, include metalaxyl, benomyl, carbofuran, fenamiphos, ethoprop, aldicarb, glyphosate, and Eptam. These can be applied after planting and have residual activity. However, the activity of these pesticides is generally narrow spectrum. Development of pest resistance to some of these fungicides may limit their usefulness. Moreover, they act as protectants or suppressants, and not as soilborne pest (plant pathogenic fungi, nematodes, insects, weeds) eradicates.

### Non-chemical (Physical Methods)

*Soil solarization*: Soil solarization is an environmentally sound, non-toxic approach with broad-spectrum activity to soilborne pathogen management. However, this approach requires a long treatment period necessitating that land be removed from production. It is not effective in cooler or cloudy climate areas. Some important weeds and soilborne pathogens (nutsedge, morning glory, and deep or high-temperature-tolerant fungal pathogens like *Armillaria* species and *Macrophomina* species) are not controlled. Fungal plant pathogen control is limited to the top 12-18 inches of soil. This is not adequate for plant parasitic nematodes, especially in deep-rooted tree and vine crops.

*Steam:* Steam is a non-toxic, environmentally sound approach to soilborne plant pathogen management. As with soil solarization, steam also has a broad spectrum of activity. However, it is not appropriate for field applications, and its use is limited to greenhouse situations and for container-grown plants. Moreover, use of steam may require high levels of energy input and may be expensive for some applications.

## Biological Control

*Antagonistic Microorganisms:* *Agrobacterium radiobacter* strain K-84 is available for the effective management of crown gall disease, caused by *A. tumefaciens*, on some crops. There are no known negative environmental or toxicological impacts. However, the spectrum of activity of microbial biological control agents in general is very narrow, being limited to specific plant pathogens or insect pests.

## Cultural Practices

*Preplant Fallow/Crop Rotation:* Use of appropriate cultural practices is an easy, environmentally compatible, non-toxic approach to management of some soilborne plant pathogens. However, this can be expensive. This approach removes land from production or often necessitates growing less valuable crops. The efficacy of this approach for soilborne plant pathogen management is not well established. Results have been inconsistent. These cultural practices are not effective against all soilborne plant pests.

*Site Selection and Modification:* Tiling, subsoiling, and berming are environmentally benign practices that can alleviate soilborne plant pathogen problems in some situations. However, these are partially effective against only a limited range of soilborne plant pathogens. In addition, site modification can be expensive.

*Soil Water Management:* Soilborne plant pathogen management based on appropriate soil water management is generally economical and environ-

mentally benign. However, this approach is limited to the management of plant diseases caused by water molds. In addition, this approach is applicable only in irrigated agricultural systems. Appropriate irrigation or water management systems are expensive to install.

## Host Resistance

*Pest Resistant/Tolerant Rootstocks and Varieties:* Host resistance is potentially the most highly effective, environmentally benign approach to management of soilborne plant pathogen and insect pests. It is economical and easy to use. However, in most cases the spectrum of activity of host resistance is limited. Moreover, plant pathogen and insect pest resistant/tolerant hosts may be horticulturally inferior to existing hosts. There may be problems with commodity or product quality control. Plant pest resistant/tolerant hosts may be more difficult and expensive to produce than standard rootstocks and varieties. This approach is not available for the control of some important diseases or disease-related problems, especially specific replant problems.

## POTENTIAL ALTERNATIVES

*Existing and New Chemicals:* Substitute or replacement chemicals for methyl bromide as a soil fumigant to manage soilborne plant pathogen and insect pests affecting tree and small fruit, and vine crops include sulfur dioxide, sodium tetrathiocarbonate, Enzone®, naturally-occurring plant products, and biorational pesticides. The regulatory acceptance of broad spectrum biocides is uncertain. Specific biorationals and natural products are likely to be expensive to develop. Nevertheless, grower acceptance and technology transfer are expected to be relatively easy.

*Physical Methods:* Electronic heating (brought about by radio frequency power) for soilborne plant pest management can use microwave, conductive, or inductive modalities. Bulk heating of soil to kill these pests is potentially economical using modern techniques. Selective heating of soilborne pests

without heating the soil is theoretically feasible by choosing microwave frequencies which excite organic molecules in these organisms without heating soil or water. This approach would reduce the energy costs at least an order of magnitude. Soil penetration of microwaves theoretically can occur to 3-4 feet depending upon wavelength. Potential harm of microwaves to users and environment can be prevented by appropriate shielding, as with standard kitchen microwave ovens. Electronic heating may be integrated with other techniques, such as soil solarization.

Improved *soil solarization* technology could increase the potential to expand the geographical range of use, and to increase efficacy for deep-rooted tree and vine crops.

*Host Resistance/Tolerance:* Potentially, development and use of rootstocks and scion cultivars/varieties with multiple plant pest resistance/tolerance is the most effective and desirable strategy for managing soilborne plant pathogens and insect pests. This approach is environmentally sound, economical, and, in some cases, persistent.

*Containerized Production:* For nursery systems, conversion to container-grown production systems using plant pathogen and insect-free or -suppressive rooting media avoids soilborne plant pest problems. Non-chemical technology is currently available for many crops. However, this is expensive.

## **Cultural Methods**

*Fertigation:* Fertigation with monoammonium phosphate may ameliorate specific replant diseases of apples. This approach is inexpensive and non-toxic. However, this approach is largely undeveloped as a soilborne plant pathogen management strategy for tree and vine crops.

*Groundcover Management:* The use of green manure, cover crops, and allelopathy to manage soilborne plant diseases is limited in the spectrum of pathogens controlled. This approach is relatively inexpensive and environmentally compatible.

However, the efficacy of this approach is largely unknown. Technology transfer is expected to be relatively easy.

*Soil Amendments and Growing Media:* The level of control of soilborne plant pathogens in field- and container-grown plants using soil amendments and various growing media is uncertain. Moreover, any control is likely to be limited in both scope and magnitude. This approach is potentially non-toxic, depending upon the source of the amendments. Large volumes, and concomitant large costs, are likely to be necessary.

*Biological Control:* The use of biological control agents, such as antagonistic or predatory organisms, for soilborne plant pathogen and insect pest management is likely to be limited in scope and magnitude. The level of pest control is uncertain. Reapplication/delivery to target sites (deep roots) may be necessary and/or difficult. Societal perception may be variable.

## **RESEARCH NEEDS**

### *High Priority, Short Term*

Improve methods of risk assessment, including soilborne plant pest (pathogens, insects and weed seeds) detection and development of action thresholds.

Evaluate existing (registered and non-registered) chemicals and develop improved application technology for soilborne plant pest management.

Evaluate existing germplasm for resistance and tolerance to specific soilborne plant insects and pathogens, including plant parasitic nematodes.

Develop improved technology for soil solarization of deep-rooted tree and vine crops under various climatic conditions.

### *High Priority, Long Term*

Develop and evaluate integrated, multi-component systems for soilborne plant pest management.

Develop new, horticulturally desirable/acceptable rootstocks and cultivars with multiple soilborne plant pathogen resistance, using traditional and novel breeding techniques.

### *Medium Priority, Short Term*

Evaluate irrigation systems for delivery of chemical pesticide and biological control agents to manage soilborne plant pathogen and insect pests.

Evaluate the feasibility of new heat treatment methods (radio frequency power) to effectively manage soilborne plant pathogen and insect pests. Develop appropriate application technology.

### *Medium Priority, Long Term*

Develop improved cultural practices for management of soilborne plant pathogens and insect pests, including cover crops, crop rotational schemes, and soil water management.

Develop and evaluate environmentally safe broad-spectrum chemical biocides/pesticides, including synthetic chemicals, naturally occurring chemicals, and biorational products.

Identify biocontrol agents, and develop appropriate formulations and delivery systems applicable to commercial tree fruit, tree nut, and small fruit crop production.

### *Low Priority, Long Term*

Evaluate soil amendments for suppression of soilborne plant pathogens and pests of tree and vine crops.

## Session VII: Solanaceous Crops

Discussion Group: *Chairs*-Joe Noling, Milt Schroth; *Participants*-Ole Becker, Dermot Coyne, David Cudney, Philip Dukes, Joe Hancock, Jim Lorbeer, States McCarter, Judy Thies, Seymour Van Gundy

### INTRODUCTION

Besides controlling a wide range of soilborne plant pests, methyl bromide also protects plants against many other unidentified, but important, subclinical plant pathogens which can also affect plant health. Without methyl bromide, these expected new pathogens, as well as new strains, will likely become of increased significance.

There are many approaches that need immediate attention in order to develop and implement economically sound alternatives to methyl bromide soil fumigation to manage a wide range of soilborne plant pests, including plant pathogens, insects, and weed seeds. Since methyl bromide is a system in itself, this will likely involve a combination of methods such as development and use of pest resistant/tolerant hosts, use of cultural practices (crop rotation), development of microbial biological control agents, and use of other worker-, consumer- and environmentally-safe chemical pesticides. That is, integrated pest management is likely to be a key strategy for soilborne plant pest management in place of methyl bromide. Short-term approaches will probably focus on development of more pest resistant/tolerant hosts, and exploring use of existing chemicals alone or in combinations. However, there is a need to accelerate development of new technologies and approaches necessary for effectively using and integrating a variety of cultural practices, biological control agents, and resistant hosts.

### COMMODITIES, PEST PROBLEMS, AND SCOPE

The commodities addressed in this section include tomato, pepper, and tobacco transplants.

### TOMATO PESTS AND SCOPE

- Fungi:**
- Pythium* damping-off is a national problem
  - Verticillium* wilt is a national problem
  - Rhizoctonia solani* damping-off is a national problem
  - Phytophthora* root rot is a national problem, but in limited areas
  - Southern blight (*Sclerotium rolfsii*) is a regional problem in the Southeast
  - Fusarium wilt (*Fusarium oxysporum*) is a regional problem in the Southeast and California
  - Corky root (*Pyrenochaeta terrestris*) is a regional problem in California
  - Root and stem rot (*Sclerotinia sclerotiorum*) is a regional problem in Florida
  - Fusarium crown (*Fusarium oxysporum*) rot is local problem in South Florida
- Bacteria:**
- Bacterial wilt (*Pseudomonas solanacearum*) is a regional problem in the Southeast
- Nematodes:**
- Root-knot nematode (*Meloidognyne* species) is a regional problem in the Southeast and localized areas in California
  - Sting nematode (*Belonolaimus longicaudatus*) is a regional problem in the Southeast

Weeds: A number of annual and perennial weeds, too numerous to list here, are recognized as pests during tomato production. Many different grasses and nutsedge were identified as major weed problems common to all areas of production.

## PEPPER PESTS AND SCOPE

Fungi: *Pythium* damping-off is a national problem  
*Rhizoctonia solani* damping-off is a national problem  
*Verticillium* is a national problem  
*Phytophthora* root rot is a national problem, but in limited areas  
Southern blight (*Sclerotium rolfsii*) is a regional problem in the Southeast  
Fusarium wilt (*Fusarium oxysporum*) is a regional problem in the Southeast  
Root and Stem rot (*Sclerotinia sclerotiorum*) is a regional problem in Florida  
Corky root (*Pyrenochaeta terrestris*) is a regional problem in California  
Fusarium crown rot (*Fusarium oxysporum*) is a local problem in South Florida

Bacteria: Bacterial wilt (*Pseudomonas solanacearum*) is a regional problem in the Southeast

Nematodes: Root-knot nematode (*Meloidogyne* species) is a regional problem in the Southeast and in localized areas in California  
Sting nematode (*Belonolaimus longicaudatus*) is a regional problem in the Southeast

Weeds: A number of annual and perennial weeds, too numerous to list, are recognized as pests during pepper production. Several different grasses

were identified, particularly nutsedge, as major weed problems common to all pepper production areas.

## TOBACCO TRANSPLANT PESTS AND SCOPE

Fungi: *Pythium* species damping-off is a regional problem in the Southeast  
*Phytophthora* species root rot is a regional problem in the Southeast  
*Thielaviopsis* species is a regional problem in the Southeast  
*Sclerotinia* species is a regional problem in the Southeast  
*Glomus* species is a regional problem in the Southeast

Bacteria: *Pseudomonas solanacearum* (bacterial wilt) is a regional problem in the Southeast

Nematodes: Root-knot nematode (*Meloidogyne* species) is a regional problem in the Southeast  
Tobacco cyst nematode (*Globodera tabacum*) is a regional problem in the Southeast

Weeds: A number of annual and perennial weeds, too numerous to list here, were recognized as pests during tobacco seedling production. Several different grasses and nutsedge were identified as major weed problems common to all tobacco seedling production areas.

Tobacco is a regional crop. All of these problems affect all Southeast United States production areas.

## EXISTING AND POTENTIAL ALTERNATIVES

### Chemical Methods

Existing/Potential Chemicals

*Fumigants:* Six broad-spectrum fumigants were identified. These are chloropicrin, Telone II®, Telone C-17®, Basimid®, metham-sodium, and Vorlex®. Without exception, all of these are generally less effective than methyl bromide or of inconsistent effectiveness, resulting in reduced crop yields and quality. Based on soilborne pest control activity, near equivalent replacement of methyl bromide and methyl bromide + chloropicrin with existing chemical alternatives will require extensive evaluation of individual, and particularly of combinations of chloropicrin with either 1,3-D (Telone®), metham-sodium (Vapam®), or dazomet (Basimid®). It is recognized that Basimid® is not currently registered for food crop uses within the United States.

Since many of the existing chemical alternatives are considerably less volatile than methyl bromide moving or diffusing through soil, failure to achieve uniform lethal concentration in soil is often reported as the primary factor contributing to partial or insufficient levels of pest control efficacy with these compounds and inconsistent crop responses. To enhance pest control efficacy with these compounds, significant improvements of existing application delivery systems, as well as chemigation (the application of compounds in irrigation water) systems, are needed.

## Non-Chemical Methods

### *Biological*

Host resistance can, in some cases (water molds, fungi, nematodes), offer a partial degree of control and/or tolerance to some pests. In most cases, however, no resistant crop cultivars are available, or are environmentally stable in areas where needed.

Many different microorganisms have been identified as potential biological control agents. However, none are currently available for commercial use in solanaceous crop production systems. Because there is a need to develop and simultaneously use multiple types of biocontrol agents against the complex of pests that frequently occur within a

given field, it is unlikely that biocontrol will develop into a practical, reliable means for soilborne plant pest management.

## Cultural Practices

*Flooding* can reduce the severity of some nematode and disease problems. However, this is not considered feasible or practical for most crop producing areas given current water use limitations and restrictions on topography. In addition, there is the potential for field spread of surviving pathogens and weed seeds during flooding.

*Fallowing of soils and crop rotations* have not been sufficiently developed to be feasible, effective alternatives for methyl bromide to manage soilborne plant pests in solanaceous crop production systems. With many pests, such as *Verticillium*, *Fusarium*, and *Meloidogyne* species, resting structures and/or the ability of the pest to infest or colonize alternative hosts allow them to survive for many years. In other cases, rotations with certain crops lead to substantial growth increase when compared to monocropping. However, at present, substantial economic losses would occur without the use of methyl bromide when fallow soils or rotation with crops of less value occur. In most cases, there is insufficient information on how best to employ such techniques as fallow soil, crop rotation, or crop sequencing to manage the soil microflora. The unavailability of suitable rotation land and specific nonhost crops suitable for multiple pest complexes is also a major constraint.

Use of *plastic mulch* is an integral component of tomato and pepper crop production systems in many areas of the United States. The benefits include partial weed control; reduced evaporation losses and maintenance of more uniform soil moisture; minimized leaching of soil agrichemicals; and reduction in incidence of some root pathogens, but an increase in others. Mulches do not now serve as an alternative to methyl bromide, but do serve to minimize water and nutrient stresses often enhancing the plant's ability to tolerate higher pest pressures.

## Physical Methods

*Steam sterilization of soil* has been used effectively in greenhouse operations and tarped soil applications. Steam is considered to be extremely slow in operation for field treatment, energy dependent, and may be potentially dangerous to field personnel. In addition, necessary equipment is expensive and difficult to obtain. Due to potential hazards, steam does not appear to be a viable alternative to methyl bromide fumigation in solanaceous crop production systems. However, it may be useful for greenhouses and, with appropriate agricultural engineering support, particularly of equipment design and alternative delivery systems, may be of limited use for small farm acreages.

*Soil solarization* may be successfully applied to manage soilborne plant pests in hot, arid climates, such as in Arizona and California. Less favorable application of soil solarization will occur in the Southeast. This approach is still in the experimental phase and insufficient data are available to adequately evaluate potential benefits with respect to soilborne plant pest management. Serious shortcomings include high cost, problems and costs of plastic disposal, limited depth of pest control, and unsuitable environmental and edaphic conditions necessary for practical, effective use. Potential use as a prestressing agent in combination with other means of soilborne plant pest management (i.e., fumigants) should be explored.

## RESEARCH NEEDS AND PRIORITIES

### *Short Term (5 Years)*

Improve methodologies to monitor population dynamics and understand microbial ecology in the soil, including pest identification techniques, microbial interactions, and other microorganism activities, of soilborne plant pests.

Extensively evaluate alternative chemicals alone and in combinations, including chloropicrin, Telone®, metham-sodium, and other herbicides.

Reevaluate existing solanaceous crop germplasm for resistance/tolerance to the major soilborne plant pests.

### *Long Term (10 Years)*

Develop and evaluate improved soilborne plant pest resistant/tolerant solanaceous crop germplasm with horticulturally or agronomically acceptable traits using both conventional and molecular techniques.

Develop integrated pest management systems, including evaluation of combinations of chemical and non-chemical approaches, for effective management of soilborne plant pests of solanaceous crops.

Identify, evaluate, and develop potential biological control agents and/or natural products to effectively manage soilborne plant pests of solanaceous crops. This should include development of appropriate delivery and application methods, as well as development of strategies that enhance the activities of biocontrol agents under natural conditions in solanaceous crop production systems.

Develop and improve crop rotation systems that most effectively suppress the activities of soilborne plant pests of solanaceous crops.

## Session VIII: Forestry, Nursery, and Ornamental Crops

Discussion Group: *Chairs*- Robert Linderman, Wayne Dixon, Stephen Fraedrich, Richard Smith; *Participants*-Larry Abrahamson, William Carey, Everett Hansen, Harvey Holt, Robert James, Jennifer Juzwik, Robin Rose, David Schisler

### INTRODUCTION

The production of forestry and ornamental crops includes a wide diversity of plant species. The plants themselves are the product, and they are grown in many different types of production systems, from bareroot in ground beds and fields to production in containers and greenhouses. These plants are produced in every part of the United States and shipped from their site of production to their site of use. Shipping, handling, storage and out planting become considerations in dealing with disease and insect problems. The geographical sites of production may have great differences in climate, soil, and pest problems. Production systems are also influenced by a variety of manager and market demands.

Methyl bromide has been widely used to control soilborne root diseases (including nematodes), insects, and weeds. The primary use of methyl bromide has been to treat ground beds. However, it has also been used to treat container mixes and containers to erradic soilborne plant pests known to limit production and quality.

### COMMODITIES, PEST PROBLEMS, AND SCOPE

The wide diversity of forestry and ornamental commodities produced in nurseries and greenhouses includes trees for reforestation, Christmas trees, landscape and ornamental purposes, as well as fruit trees and small fruits.

The soilborne pests of these commodities include pathogens, nematodes, insects, and weeds. The

scope of these problems is national or regional. Additional problems are expected to arise and the scope of current problems will increase if methyl bromide is not available for use in producing these commodities.

### Pathogens

Soilborne fungal pathogens include *Fusarium*, *Pythium*, *Phytophthora*, *Rhizoctonia*, *Cylindrocladium*, and *Verticillium*, which are national problems. Regional problems are caused by *Macrophomina* in the South and West, and *Phoma* in the West.

Soilborne bacterial pathogens include *Agrobacterium* and *Erwinia*, which are national problems, and other deleterious bacteria which are a regional problem in the West.

### Nematodes

Plant parasitic nematodes are a national problem and include a large number of species. Different species may be important in each region. Estimated world basis annual yield losses due to damage by plant parasitic nematodes on ornamental plants is 11.1%. Meloidogyne species are a major problem in container grown ornamentals.

### Insects

Cutworms, white grubs, and root weevils are national problems. Regional insect problems include lesser cornstalk borer, pine sawflies, fire ants, mole crickets, and ground pearls in the south; sod and pine webworms in the North and South; cranberry girdler and black vine weevil in the North and West; root aphids, strawberry weevils, and western flower thrips in the West; and fungus gnats in the South and West.

## Weeds

Spurges, nutsedges, grasses, chickweeds, hardwood trees, pigweed, clover, thistle, mustards, geraniums, and mosses and liverworts are national weed problems. Regional weed problems include bird's foot trefoil in the West; and sicklepod and carpet weed in the South.

## EXISTING ALTERNATIVES

*Other Chemicals:* Some fumigants such as Basimid® and metham sodium are available for use in the production of forest-tree seedlings and ornamental crops. In addition, fungicides (for chemical drenches, root dips and seed treatments), herbicides (including mineral spirits), and insecticides are available to control some soilborne diseases, insects, and weeds. However, none of these alternative chemicals appear to be as effective as methyl bromide. Also, these chemicals may be potential environmental contaminants, may pose health and safety concerns, and may require more time, labor, and space allocations. The future use of at least some of these chemicals is likely to be limited by regulatory challenges and uncertain legal longevity.

*Cultural Practices/Systems:* Management of some soilborne plant pests of forestry, nursery, and ornamental crops may be achieved to a limited extent by crop rotations, fallowing, water management, soil amendments, cover crops, intercropping, mulches, and sowing. These cultural practices are currently available, environmentally compatible, conserve beneficial soilborne organisms, and are subject to no or minimum regulation. However, they are not uniformly applicable nationally, require more land, are labor intensive, require a greater knowledge base, are potentially more variable qualitatively, may be more site and problem specific, may cause damage to soil properties, and require increased energy consumption and equipment maintenance.

*Physical Methods:* Physical methods that may be used to a limited extent for managing some soilborne plant pests of forestry, nursery, and ornamen-

tal crops include soil solarization, heat pasteurization using steam, flaming for weeds post emergence, cultivation of weeds, mechanical weeding, hand weeding, mulching, composting, trapping, and physical barriers. These methods are generally readily available, broad spectrum, environmentally benign, subject to minimal regulation, and, some at least, have a short turn-around time. Soil uniformity and altered microbial ecology may be adversely impacted by some of these methods. Primary disadvantages of these methods include tarp disposal problems, increased energy costs, reduced efficacy, and smaller/narrower windows of opportunity.

*Biological Control:* Biological control systems can be used to a very limited extent for the control of some soilborne pests in the production of forest-tree seedlings and ornamentals. These systems are based on the use of bioactive composts, soil amendments, beneficial organisms (predators, parasitoids, parasites, competitors, antagonists), pheromones, bioherbicides, and bioinsecticides. A narrow pest specificity may be a problem with some of these methods. Other disadvantages include: a lack of uniform quality, unknown compatibility with other treatments, a need for repeated applications in some cases, transportation of compost, reduced efficacy and increased variability of pest control, potential toxicity from high salts and heavy metals in composts, as well as a limited knowledge base from which to work. A major positive attribute of biological control practices is that they are generally considered to be environmentally acceptable.

## POTENTIAL ALTERNATIVES

*Other Chemicals:* Anhydrous ammonia, re-registered pesticides, pesticides with expanded use labels, new combinations of existing and available chemical pesticides, and naturally occurring pesticides are potential alternatives to methyl bromide for controlling soilborne pests of forestry, nursery, and ornamental crops. However, many of these approaches have not yet been developed sufficiently for widespread use. Other limitations include possible adverse environmental impacts,

longer post-treatment waiting period, regulatory challenges, and uncertain legal longevity.

*Integrated Pest Management Systems:* Methyl bromide has been the central focal point of many pest management programs in forest-tree nurseries and for the production of ornamental crops. The regulatory withdrawal of methyl bromide (and possibly of other pesticides) will necessitate an increasing reliance on more complex integrated pest management systems in the future. These systems will incorporate existing and potential cultural, physical, biological, and chemical control practices.

Short term (2-6 years): It is imperative that integrated pest management programs be developed for the short-term to ensure that the removal of methyl bromide causes minimal disruption of nursery and greenhouse operations that produce forest-tree seedlings and ornamental crops. These integrated pest management programs would emphasize the integration of existing cultural, physical, biological, and chemical control practices. Included in these programs would be the use of other existing soil fumigants, as well as other pesticides where appropriate. Investigations are needed on the timing of applications, determining rates, and how best to apply and utilize other existing pesticides (including alternative soil fumigants). An emphasis should be placed on minimizing pesticide use by maximizing understanding of when, how, and at what rates to use pesticides.

Long-term (more than 6 years): Issues regarding environmental quality, and concerns over public health and safety are likely to only become progressively greater with time. Therefore, the use of many currently-existing soil fumigants and other pesticides may be questioned in the future. Crop production managers will be forced to rely increasingly on non-chemical control strategies. It is therefore imperative that long-term research efforts be initiated on the development of biologically-based, environmentally-sound integrated pest management programs. These programs should emphasize the integration of existing and potential cultural, physical, and biological cultural control

practices. Integration of environmentally-safe chemical control practices that target specific organisms should be emphasized. Host resistance should be utilized where appropriate and economically feasible. Methods to detect pest population levels and accurately forecast their impact are essential and need to be developed.

*Cultural Practices:* In addition to further developments and refinements to increase efficacy of cultural practices described under “Existing Alternatives”, potential pest control practices also include: improved irrigation systems; better sowing technology; new cultivation technology; survey and detection systems; refinements in compost technology; and integration of practices to maximize pest control.

*Physical Methods:* Soil solarization, composting, irradiation, electronic heating (microwave), insect trapping, physical barriers such as mulches, matting and soil stabilizers, and greenhouse heating are broad spectrum, environmentally benign approaches. Many of these technologies are available; however, they have not been sufficiently developed for widespread use to manage soilborne pests of forestry, nursery, and ornamental crops. Some of these provide a short turn-around time. These approaches are subject to minimal regulation. Problems associated with these approaches include tarp longevity and disposal, greater energy costs, reduced efficacy, smaller/narrow window of opportunity, negative public perception of irradiated product, and worker safety with irradiation and microwave equipment. Composting and new cultivation technology are needed.

*Biological Control:* Biological control systems for soilborne pest management for forestry, nursery, and ornamental crops are based on introduction, augmentation, and conservation of biocontrol agents; enhancement of resident microbes; microbial combinations; insect behavior modification chemicals; and allelopathy. These systems are generally environmentally sound, but may be of limited use due to narrow pest specificity. Other limitations include unknown compatibility with other treatments, need for repeated applications,

reduced efficacy and increased variability of pest control, and the currently limited available knowledge base. Improved production, formulation, and delivery technologies for microbial antagonists need to be developed. Microbial antagonist combinations need to be evaluated. Biological control strategies need to be integrated with cultural and chemical approaches.

*Genetics/Biotechnology:* Genetics and biotechnology are potential approaches to developing pest-resistant hosts through gene transfer or induced pest resistance. These approaches were considered to be largely impractical as a means of pest control in the production of forest and ornamental crops, because of the wide diversity of plant species grown and the large number of pest problems encountered

*Detection Systems:* Biotechnological approaches may be used to identify specific organisms and to distinguish pathogenic organisms from non-pathogenic and beneficial microorganisms. Such systems are highly desirable for use in any integrated pest management program. Potential negative aspects are the high cost of biotechnologically-derived products.

*Host Resistance:* Plant breeding and biotechnology are potential approaches to developing pest-resistant hosts through gene transfer or induced plant resistance. Widespread development and use of pest resistant hosts was generally considered to be impractical as a replacement to methyl bromide for forest tree nurseries and ornamental crops. The primary reasons were the large diversity of plant species grown and the large number of pest problems encountered in the production of forestry and ornamental crops. Generally, host resistance is an environmentally benign approach to pest management. Biotechnology approaches to developing pest-resistant hosts could result in lower production costs, less cultural management, and increased energy efficiency. Moreover, host resistance to pests is compatible with other pest management systems or treatments. In most cases, pest resistance is limited to a specific pest. Major limitations include impracticality due to crop diversity,

expensive development and final products, long development time, uncertain public acceptance of biotechnology-derived plants and plant products, limited knowledge of sources of pest resistance genes and technology to identify, isolate, transfer and manipulate, and overly optimistic expectations.

## RESEARCH NEEDS AND PRIORITIES

### *High Priority, Short Term*

Develop integrated pest management systems that make maximum use of existing chemical, cultural, physical, and biological control practices.

Develop new chemicals and chemical application technology. The emphasis in the short term should include timing of application, determining rates, and how best to apply and utilize other existing pesticides (including alternative soil fumigants). An emphasis should also be placed on minimizing pesticide use by maximizing understanding of when, how, and at what rates to use pesticides.

Develop new culture/crop production systems. Improve the efficacy of currently available cultural control systems. Test local effective methods on a broader basis. Conduct research to better understand the basis for their effectiveness.

### *High Priority, Long Term*

Develop new culture/crop production systems and integrate appropriate existing cultural practices. Conduct research that develops a fundamental knowledge on cultural control practices and use this knowledge to develop new and improved systems.

Develop biologically-based, environmentally-sound integrated pest management systems that place increasing emphasis on the integration and use of cultural, physical, and biological control practices. Integration of plant resistant hosts into these systems should be emphasized only where applicable and economically feasible. Emphasis should be placed on the use of safer chemicals that affect specifically the target organisms.

Develop physical pest management treatments and integrate into crop production systems. Increase research on soil solarization, pastuerization, and heat treatment methodologies.

Develop methods to detect pest population levels and accurately forecast their impact.

*Medium Priority, Short Term*

Develop physical pest management systems

Develop biologically pest control management systems, including the development of basic knowledge and a fundamental understanding of biological pest control.

*Medium Priority, Long Term*

Develop biologically pest control practices, including the development of basic knowledge and a fundamental understanding of biological pest control.

Develop new chemicals and chemical application technology.

*Low Priority, Short Term*

Develop pest-resistant hosts by breeding and biotechnology appraoches.

*Low Priority, Long Term*

Develop pest-resistant hosts by breeding/ biotechnology.

## Session IX: Leafy and Other Vegetables

Discussion Group: *Chairs*-Paul Backman, Bill Johnson; *Participants*-Harry Agamalian, Jose Amador, Bob Cartwright, R. B. Chalfant, Chuck Eckenrode, Robert Lumsden, John Radewald, Don Sumner, Geoffrey Zehnder

### INTRODUCTION

Generally, field plantings of leafy and other vegetables have relied on the use of methyl bromide as the primary means of control of plant-parasitic nematodes, soilborne plant pathogenic fungi, and most weeds. In most cases, there are only a few labeled chemical alternatives for soilborne pest management for these minor crops. No single product is available that can substitute for or replace methyl bromide. The alternative chemicals that are available are less effective and are of equal or greater cost than methyl bromide.

### COMMODITIES, PEST PROBLEMS, AND SCOPE

The leafy and other vegetable commodities considered here were carrot, cucumber, melons, and sweet potatoes. In addition, transplant production of cabbage, celery, sweet potato slips, and asparagus crowns were considered, as methyl bromide use is limited but significant for the production of these crops. It was noted that field-grown ginger production is also dependent on the use of methyl bromide.

The most important soilborne pests for these crops include eight genera of fungi, seven genera of nematodes, one bacterial genus, and two types of insects. Primary weed pests include sedges and annual weeds.

The scope of these problems is national or regional depending upon the specific soilborne pest and commodity. Losses may well be severe without development of replacement technologies.

### EXISTING ALTERNATIVES

#### Chemical Methods

*Other Chemicals:* The only chemical alternatives to methyl bromide which are available for production of these minor vegetable crops are metham-sodium (Vapam®), 1,3, dichloropropene (Telone II®), chloropicrin, and combination mixtures of these. Vorlex® is not considered to be an available alternative since the registrants are canceling the re-registration process. Fumigants that are still available may themselves face cancellations in the near future. Additional alternatives must be found.

#### Non-chemical Methods

Currently available non-chemical alternative approaches for the management of soilborne pests of these minor vegetable crops include the use of pest-resistant/tolerant host cultivars, alterations of cultural practices, and manipulation of cropping systems. None of these approaches is capable of achieving methyl bromide level soilborne pest management.

### POTENTIAL ALTERNATIVES

#### Chemicals

*Other Chemicals:* Basimid®, a methylisothiocyanate-generating product, could be available in 3-5 years. This product is similar in effectiveness to metham-sodium. Combinations of individual nematicides, fungicides, herbicides, and insecticides could be used in place of methyl bromide; however, only a few acceptable chemicals are currently registered for use on these minor vegetable crops.

## **Non-chemical Methods**

Potential non-chemical alternative approaches for soilborne pest management in these minor vegetable crops in place of methyl bromide include soil pasteurization, integrated pest management strategies, and transplant production systems that incorporate beneficial microorganisms for growth promotion and disease suppression.

## **RESEARCH NEEDS AND PRIORITIES**

### **Short Term (1-7 Years)**

Integrate existing registered fumigants and non-volatile pesticides with application technologies into soilborne pest management and minor vegetable production systems

Evaluate existing vegetable germplasm for resistance to major soilborne pests

Develop vegetable cropping systems and cultural practices based on basic understanding of the biological and ecological characteristics of soilborne plant pests to expand integrated pest management options

Accelerate evaluation of existing and new chemicals, and expansion of available pesticide labels, for management of soilborne pests of minor vegetable crops

Develop systems to produce high-quality vegetable transplants inoculated with beneficial microorganisms to assure early season plant health in field plantings

Develop and evaluate soil pasteurization techniques for crop production beds and fields, such as soil solarization, electronic heat (microwave) and steam

### **Long Term (more than 7 Years)**

Develop bio-intensive integrated pest management systems using biological control agents for soilborne pests in conjunction with applications of soil amendments and timely applications of chemicals.

Identify and develop pest resistant/tolerant crop germplasm and varieties utilizing conventional and biotechnological techniques.

Develop biological soilborne pest control systems utilizing nemato- and entomopathogens, plant growth and health promoting rhizobacteria, induced resistance, predators, parasites, parasitoids, microbial herbicides, and fungal pathogen antagonists.

Develop suppressive soils for management of soilborne plant pests in vegetable production systems.

Develop enhanced technology transfer through training of extension personnel, scouts, and consultants in biointensive integrated pest management for vegetables.

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## Appendix II

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